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EDITED BY

K. HEADLAM-MORLEY

SECRETARY



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1940

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## PREFACE.

THE present volume contains nine papers presented at the Annual General Meeting held in London on May 2nd and 3rd, 1940, together with the discussions and correspondence on them. As the publication of the Special Report Series has been discontinued, papers describing researches of the Joint Committees of the Iron and Steel Institute and the British Iron and Steel Federation and other investigations which would otherwise have been included in these Reports are now included in the *Journal of the Iron and Steel Institute*. Of the papers in this volume, two are sponsored by the Committee on the Heterogeneity of Steel Ingots, one by the Alloy Steels Research Committee and one by the Corrosion Committee. Similarly, as the *Carnegie Scholarship Memoirs* are no longer published, a report of work done with a grant from the Andrew Carnegie Research Fund is included in this volume.

As in preceding years, the volume is divided into two main Sections. Section I. opens with the Minutes of Proceedings, including the speeches made at the Members' Luncheon, which took the place of the Annual Dinner this year, the Report of Council and Statement of Accounts for 1939 and the papers enumerated above.

Section II. is devoted to a survey of literature on the manufacture and properties of iron and steel and kindred subjects, and consists of a collection of abstracts of articles from the Transactions and Proceedings of scientific societies and from the technical press. This Section also contains reviews of recent books and bibliographies of literature dealing with the manufacture and properties of iron and steel. The matter included in this Section has already appeared in the *Bulletin of the Iron and Steel Institute*, which is issued monthly.

In front of the title page is inserted a list of British Standardised Steel Samples issued jointly by the Iron and Steel Institute and the National Physical Laboratory, showing where and on what terms the samples are available. Proposal forms for Membership and Associateship and also for Joint Membership of this Institute and the Institute of Metals will likewise be found in the same place.

4, GROSVENOR GARDENS,

LONDON, S.W.1.

July, 1940.



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## ABBREVIATIONS USED IN TEXT.

Å.	Ångström unit(s).	kg.	kilogramme(s).
A.C.	air-cooled; alternating current.	kg.cal.	kilogramme-calory; -calories.
A.H.	air-hardened.	kg.m.	kilogramme-metre(s).
amp.	ampère(s).	km.	kilometre(s).
amp.hr.	ampère-hour(s).	kVA.	kilovolt-ampère(s).
atm.	atmosphere(s) (pressure).	kW.	kilowatt(s).
Bé.	Baumé (scale).	kWh.	kilowatt-hour(s).
b.h.p.	brake horse-power.	lb.	pound(s).
B.o.T.	Board of Trade.	L.F.	low-frequency.
B.Th.U.	British thermal unit(s).	m.	metre(s).
C.	centigrade (scale).	m.amp.	milliampère(s).
cal.	calory; calories.	mV.	millivolt(s).
c.c.	cubic centimetre(s).	max.	maximum.
c.d.	current density.	mg.	milligramme(s).
c.g.s.	centimetre-gramme-second unit(s).	min.	minimum; minute(s).
cm.	centimetre(s).	ml.	millilitre(s).
coeff.	coefficient.	mm.	millimetre(s).
const.	constant(s).	m.m.f.	magnetomotive force.
c.p.	candle-power.	N.	normal (solution).
cu.	cubic.	N.T.P.	normal temperature and pressure.
cwt.	hundredweight(s).	O.H.	open-hearth; oil-hardened.
D.C.	direct current.	O.Q.	oil-quenched.
dia.	diameter(s).	oz.	ounce(s).
dm.	decimetre(s).	p.d.	potential difference.
e.m.f.	electromotive force.	pH	hydrogen-ion concentration.
F.	Fahrenheit (scale).	r.p.m.	revolutions per minute.
ft.	foot; feet.	sec.	second(s).
ft.lb.	foot-pound(s).	sp. gr.	specific gravity.
g.	gramme(s).	sq.	square.
gal.	gallon(s).	T.	tempered.
H.F.	high-frequency.	temp.	temperature.
h.p.	horse-power.	V.	volt(s).
h.p.hr.	horse-power-hour(s).	VA.	volt-ampère(s).
hr.	hour(s).	Wh.	watt-hour(s).
in.	inch; inches.	W.Q.	water-quenched.
in.lb.	inch-pound(s).	yd.	yard(s).
K.	absolute temperature (Kelvin scale).	°	degree(s).

SECTION I.

*MINUTES OF PROCEEDINGS  
AND PAPERS OF  
THE IRON AND STEEL INSTITUTE.*


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ANNUAL MEETING

1940

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Editorial assistance has been given by A. E. CHATTIN, B.Sc. (Hons. Met.), A.I.C.,  
Assistant Secretary, in the preparation of this Section.



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MINUTES OF PROCEEDINGS  
AND  
PAPERS AND DISCUSSIONS  
AT THE  
ANNUAL MEETING, 1940.

THE SEVENTY-FIRST ANNUAL MEETING OF THE IRON AND STEEL INSTITUTE was held at the Offices of the Institute, 4, Grosvenor Gardens, London, S.W.1, on Thursday and Friday, May 2 and 3, 1940. In the absence through illness of the Retiring President, the Rt. Hon. the Earl of Dudley, M.C., Mr. JAMES HENDERSON (Vice-President and Hon. Treasurer) occupied the Chair at the commencement of the proceedings, his place being afterwards taken by Mr. JOHN CRAIG, C.B.E., D.L., the President-Elect.

THURSDAY MORNING, MAY 2, 1940.

The Meeting opened at 10 A.M. on Thursday, May 2, 1940, Mr. JAMES HENDERSON (Vice-President and Hon. Treasurer) being in the Chair.

The minutes of the previous meeting were taken as read and signed.

*Illness of the Rt. Hon. the Earl of Dudley, M.C.*

The CHAIRMAN (Mr. James Henderson) said that as Senior Vice-President it was his duty to take the Chair in Lord Dudley's absence. Lord Dudley was, unfortunately, indisposed.

The SECRETARY (Mr. K. Headlam-Morley) announced that a message had been received that morning to say that Lord Dudley had been taken ill and greatly regretted his inability to attend the meeting; he asked that his apologies should be conveyed to all present.

The CHAIRMAN said he was sure the Members would wish a message to be sent to Lord Dudley expressing their sincere regret at his absence and their heartiest wish that he would quickly recover his usual health. (*Hear, hear.*)

*Welcome to Members Attending the Meeting.*

The CHAIRMAN (Mr. James Henderson) said that, on behalf of the Council, he welcomed the Members, and especially those from overseas. There were present representatives from the Dominions and from France and Poland, and he extended a particularly hearty welcome to them. (*Hear, hear.*)

*Ballot for the Election of New Members and Associates.*

Mr. R. F. TYLECOTE (Manchester) and Mr. D. W. EDISON LLOYD (London) were appointed scrutineers of the ballot, and they subsequently reported that the following forty-five candidates for membership and twenty-five candidates for associateship had been duly elected.

## MEMBERS.

ANDERSON, JAMES AITKEN . . .	Sheffield.
BEHRENDT, CARL AUGUST JULIUS . . .	Scunthorpe, Lincolnshire.
BERTRAND, PIERRE . . .	Paris, France.
BLEAKNEY, HENRY H., B.Sc. . . .	Rockliffe, Ottawa, Canada.
BOK, LOUIS DENNIS CORYDON, M.Sc., Dr. rer. nat. . . . .	Vereeniging, Transvaal, S. Africa.
CARRINGTON, ARTHUR HENRY . . .	Slough, Buckinghamshire.
CASHMORE, HERBERT MAURICE . . .	Birmingham.
DEPRALON, LÉON . . . . .	Indret (Loire Inférieure), France.
DERRY, LESLIE WATSON, B.Sc.(Birm.), M.Sc.Tech. (Manchester) . . .	London.
FAIRLEY, Dr. THOMAS, M.Sc. . . .	Loughborough, Leicester- shire.
FARROW, FREDERICK DENNY, M.Sc. (N.Z.) . . . . .	London.
FULLER, TRUMAN SAMUEL, B.S. . . .	Schenectady, New York, U.S.A.
GREEN, WILFRED BULLER, B.Sc.(Hons.), A.M.I.E.E. . . . .	Rugby, Warwickshire.
HARDWICK, JOHN VINOR . . . . .	Rugby, Warwickshire.
HOOD, FREDERICK JOHNSON . . . .	Solihull, Warwickshire.
HOOKHAM, GEORGE . . . . .	London.
JACKSON, HENRY HERBERT . . . .	Coventry.
JENKS, WILFRED ALBION . . . . .	Warrington.
KIEFT, CYRIL WILLIAM . . . . .	Wellington, Shropshire.
KLINE, ELMER, B.S. . . . .	Huntington, W. Va., U.S.A.
KUROKAWA, KÊRIRÔ . . . . .	Nihon Seikôsho, Muroran, Japan.
LAWRENSON, RALPH . . . . .	Alexandria, N.S.W., Australia.
LEETCH, SAMUEL . . . . .	Stockton-on-Tees.
LEPP, HENRY, Dr. Ing. . . . .	Cabourg (Calv.), France.
LITCHFORD, Major EDWARD ROWLAND	London.
OLIVER, DONALD ARTHUR, M.Sc. . .	Sheffield.
O'SULLIVAN, PATRICK . . . . .	Ilford, Essex.

PARRY, JOHN HENRY . . .	Birmingham.
PEHRSSON, ERIK GUSTAF . .	Sandviken, Sweden.
PHILLIPSON, GEORGE CLEMENT . .	Partington, near Manchester.
PORTEOUS, JOSEPH, B.Sc. . .	Newcastle, N.S.W., Australia.
SANDBERG, STANHOPE PETER ALEXANDER FORBES, B.A.(Cantab.)	London.
SCOTT-KING, ALEC . . .	Swansea.
SMITH, FRANK EWART, M.A.(Cantab.)	Billingham, Co. Durham.
SYKES, CHARLES, D.Sc., Ph.D., F.I.P.	Teddington, Middlesex.
TANN, JIFF P. . . . .	Sheffield.
TISDALE, NORMAN FENWICK, B.Sc. .	Pittsburgh, Pa., U.S.A.
TROUGHTON, ERNEST ROBERT, O.B.E.	London.
UEDA, <i>Engineer Commander</i> HIROSI .	London.
WAINWRIGHT, HECTOR AITKEN, B.Eng., M.Met., A.M.I.E.E. . .	Sheffield.
WESTBERG, SIGURD . . . .	Rotherham.
WILLIAMS, CHARLES GARRETT, B.Sc.(Hons. Lond.), M.Sc. (Vict.) .	Brentford, Middlesex.
WYGARD, EDWARD J. . . . .	London.
WYLLIE, MALCOLM ROBERT JESSE, B.Sc. . . . .	Vereeniging, Transvaal, S. Africa.
YONEMASU, KENJIRO . . . .	Hayashida, Kobe, Japan.

## ASSOCIATES.

BROWN, HENRY THOMAS GODFREY .	Ipswich, Suffolk.
CHOUDHURI, KIRAN CHANDRA, M.Sc.	Leeds.
COPPOLA, RONALD FREDERICK . .	Greenford, Middlesex.
EDGE, THOMAS . . . . .	Manchester.
GREEN, DAVID FREDERICK . . .	London.
KINGSWOOD, VICTOR SALVATORE, B.Sc.(Hons.) . . . . .	London.
KONDIC, VOJISLAV . . . . .	Birmingham.
KREITLING, LAWRENCE LEONARD .	Derby.
KRISHNASWAMY, NADATHOOR R. .	London.
LARDNER, EDWIN, B.Sc.(Hons.) .	Birmingham.
LAW, STANLEY WENTWORTH . . .	Corby, near Kettering, Northamptonshire.
LEWIS, FREDERICK VICTOR . . .	Wirral, Cheshire.
LLOYD, CHARLES A. . . . .	Birmingham.
LUNN, DUDLEY CHARLES FARNDON .	Greenford, Middlesex.
MANCE, HERBERT WILLIAM . . .	Godalming, Surrey.
MATHIAS, ERNEST VICTOR . . .	Renfrew, Scotland.
MERCHANT, HERBERT JOSEPH . .	Kidderminster.
NILSSON, KARL FOLKE . . . . .	Hagfors, Sweden.
PICKMAN, DAVID OPENSHAW . . .	Stockport, Cheshire.
SINGH, SUJAN . . . . .	Colony, Lahore, India.
SKELTON, LESLIE GEORGE VICTOR .	London.
SNODGRASS, COLIN BRODIE . . .	Swansea.
TOTTLE, LESLIE GOODRIDGE . . .	Coventry.
WHITAKER, JOHN KENNETH . . .	Manchester.
WOGIN, REGINALD . . . . .	Scunthorpe, Lincolnshire.

*Presentation of the Report of Council and Statement of Accounts  
for 1939.*

The CHAIRMAN (Mr. James Henderson) suggested that, in accordance with usual practice, the Report of Council and Statement of Accounts for 1939 (*see pp. 19 P-51 P*) should be taken as read. (*Agreed.*)

The Chairman, commenting briefly on the Report and Accounts, said that the Institute mourned the loss of forty-five Members, including three Members of Council—Professor Henry Louis, Monsieur Alexandre Dreux and Mr. Charles Schwab—all of whom had been distinguished members of the industry. He asked those present to stand for a few moments in silence as a token of respect.

He formally moved the adoption of the Report of Council and Statement of Accounts.

Mr. P. B. BROWN (Member of Council) seconded the motion, which was carried unanimously.

*Induction of the President-Elect, Mr. John Craig, C.B.E., D.L.*

The CHAIRMAN (Mr. James Henderson) said that as Lord Dudley's term of office was closing, the Council had invited Mr. John Craig to succeed him. He knew of no one who could fill this honourable position with more dignity and confidence. Mr. Craig could count on their help during what must necessarily be a difficult period of office and one of critical importance to the Institute.

Mr. HENDERSON then vacated the Chair, which was taken, amid applause, by the incoming President, Mr. JOHN CRAIG.

*Vote of Thanks to the Retiring President.*

The PRESIDENT (Mr. John Craig) said his first duty was to thank Mr. Henderson for the terms in which he had inducted him into the Chair. He would call upon Sir Peter Rylands to move a vote of thanks to the retiring President, Lord Dudley.

Sir PETER RYLANDS, Bt., J.P. (Past-President), said that it was unfortunate that Lord Dudley was unable to be present to receive their thanks for his services to the Institute during his term of office, for they wished to express their appreciation in an almost more emphatic way than usual.

Lord Dudley had rendered great services to both the Institute and the industry. He had been concerned with the Institute's move to its present splendid building, and it was largely his inspiration that had enabled the financial obligation thus incurred to be met. He had likewise played an important part in recent years (during one of which he had been President of the British Iron and Steel



Federation) in the relations that had been entered into overseas—with the Cartel on the Continent, and in the Dominions—which were of outstanding importance to the iron and steel industry.

Captain R. S. HILTON (Member of Council) seconded the resolution, and the vote of thanks was carried unanimously, with acclamation.

*Election of Vice-Presidents and Members of Council.*

The SECRETARY (Mr. K. Headlam-Morley) said that, in accordance with Bye-Law 10, the names of the following Vice-Presidents and Members of Council had been announced at the Autumn Meeting, 1939, as being due to retire at the present Annual Meeting :

*Vice-Presidents :* Sir William Larke, K.B.E.; Mr. A. O. Peech; Dr. C. H. Desch, F.R.S.

*Members of Council :* Mr. E. J. Fox; Dr. T. Swinden; Dr. A. McCance; Mr. P. B. Brown; Mr. J. R. Menzies-Wilson.

No other Members having been nominated up to one month previous to the present meeting, the retiring Members were now presented for re-election. (*Agreed.*)

*Presentation of the Bessemer Gold Medal for 1940 to  
Dr. Andrew McCance.*

The PRESIDENT (Mr. John Craig) announced that the Council had decided to award the Bessemer Gold Medal for 1940 to Dr. Andrew McCance. (*Applause.*) The award was made in recognition of Dr. McCance's great services to the scientific study of the problems of steelmaking, with special reference to the application of the rules of physical chemistry to the open-hearth process and his critical examination of the thermo-chemical equations governing the process, and in recognition of the numerous contributions that he had made to the *Journal* of the Institute and to other scientific publications, the researches he had conducted and the encouragement which he had given to research by others, his services to the steel industry in Scotland, including especially the introduction of the manufacture of alloy steels, and the valuable work he had done in introducing modern technical developments into British steelworks.

That was the official statement prepared by the Council justifying the award of the Medal to Dr. McCance, and personally he would supplement it because he knew the great contributions which Dr. McCance had made to the industry as a whole, and particularly his contributions to the industry in Scotland. Although the Bessemer Gold Medal would ever be treasured by Dr. McCance as a high honour, there were other monuments to his greatness which would remain in Scotland long after the memory of the Medal had faded, at any rate from other minds than his own, and they would be the works in Scotland which had been erected and which bore his stamp,

carrying out his ideas, and enabling the industry in Scotland worthily to maintain its place among the steelmaking industries of the whole world. Dr. McCance brought to his duties not only a highly trained scientific mind, but also a wonderful ability to mingle the science with the art.

The President then, amid applause, handed the Bessemer Gold Medal to Dr. McCance.

Dr. ANDREW McCANCE, in thanking the President and the Council of the Institute, said that to have one's name associated with that of Bessemer, no matter in how remote a degree, was an aspiration near to the heart of every metallurgist. In his own case, by being the recipient of the Bessemer Gold Medal he felt that he had achieved that aspiration, although the slender thread of association was merely a common interest in the practice and theory of steelmaking, a subject which he had always found full of attractions. To-day, as in the days of Bessemer, it must be admitted that the practice of the art was still ahead of the theory, but the gap between the two was lessening, and nowhere more so than in Britain, of which the standard of steelmaking technique was not surpassed by that of any other country. In that situation the work of the Institute had played an important part; steelmaking was so fundamental to the whole economics of the iron and steel industry that it could never receive too much attention.

He greatly appreciated the President's remarks, though they were biased too generously in his favour. Anything that he had been able to accomplish in the technical reorganisation of the steel-works with which both he and the President were associated could never have been achieved without the President's help and encouragement, and it was a great pleasure to receive the Medal at his hands.

*Election of M. Eugène Schneider, D.Sc., to Honorary Membership.*

The PRESIDENT (Mr. John Craig) announced that the Council had elected Monsieur Eugène Schneider, D.Sc., to Honorary Membership, in commemoration of the fiftieth anniversary of his becoming a Member of the Institute. Many of the Members, he said, knew Monsieur Schneider well, and all of them knew him by reputation. He was President of the Institute from 1918 to 1920, being one of the three non-British Presidents. He received the Bessemer Gold Medal in 1930. He had always taken a keen interest in the affairs of the Institute, and it was largely with his assistance that meetings of the Institute had been held in France, Czechoslovakia and Luxemburg. It had been hoped that he might be present that day, but urgent Government work had made that impossible. The members would look forward to his being their guest after the war. (*Applause.*)

The following telegram had been received from Monsieur Schneider :

" Please accept for yourself and convey to all colleagues my best wishes for a successful gathering. Greatly disappointed that unexpected circumstances prevent me joining you and expressing in person my heartfelt appreciation of the distinction conferred upon me by electing me Honorary Member. Permit me to offer my warmest congratulations to British steel industry upon its splendid effort in support of Allied cause. SCHNEIDER." (*Applause.*)

It would be the wish of the Members that he should acknowledge that telegram, and express their cordial appreciation of it and their renewed good wishes.

#### *Presentation of the Williams Prize for 1939.*

The PRESIDENT (Mr. John Craig) announced that the Williams Prize for 1939 had been divided between Mr. W. B. LAWRIE, for his paper on " The Refining of Metal in the Basic Open-Hearth Furnace. The Influence of Fluorspar on the Process," and Mr. W. T. WILSON, for his paper on " The Rolling of Sections at the Appleby-Frodingham Steel Co., Ltd."

#### *Award of the Andrew Carnegie Silver Medal for 1939.*

The PRESIDENT (Mr. John Craig) announced that the Andrew Carnegie Silver Medal for 1939 had been awarded to Mr. Bo O. W. L. LJUNGGREN for his paper on " Method of Sclero-grating Employed for the Study of Grain Boundaries and of Nitrided Cases; Grain Structures Revealed by Cutting."

#### *Ablett Prize for 1940.*

The PRESIDENT (Mr. John Craig) recalled that Captain C. A. ABLETT, O.B.E., B.Sc., M.Inst.C.E., had offered a Prize of £50 for a paper on a subject connected with engineering in an iron or steel works written by a junior engineer. No paper had been submitted during the year. He was pleased to say, however, that Captain Ablett had re-offered the Prize for competition by papers submitted for the Annual Meeting in 1941, and the Council had gladly accepted his offer.

#### *Presentation of the Presidential Address.*

The PRESIDENT (Mr. John Craig) then delivered his Presidential Address. The text will be found on pp. 53 P-62 P.

Sir WILLIAM LARKE, K.B.E. (Vice-President), proposed a cordial vote of thanks to the President for his most interesting, informative and inspiring Address.

Dr. W. H. HATFIELD, F.R.S. (Vice-President), seconded the vote of thanks, which was carried with acclamation.

*Complete List of Papers Presented at the Annual General Meeting, 1940.*

- A. J. BRADLEY, F.R.S., W. L. BRAGG, F.R.S., and C. SYKES : "Researches into the Structure of Alloys."
- G. P. CONTRACTOR and F. C. THOMPSON : "The Damping Capacity of Steel and Its Measurement." (Paper No. 1/1940 of the Alloy Steels Research Committee.)
- U. R. EVANS : "Report on Corrosion Research Work at Cambridge University Interrupted by the Outbreak of War." (Paper No. 1/1940 of the Corrosion Committee.)
- E. GREGORY : "Anti-Piping Compounds and their Influence on Major Segregation in Steel Ingots." (Paper No. 1/1940 of the Committee on the Heterogeneity of Steel Ingots.)
- WM. A. HAVEN : "Manufacture of Pig Iron in America."
- H. LEPP : "The Oxygen/Hydrogen/Molten-Iron System."
- BO O. W. L. LJUNGGREN : "Method of Sclero-grating Employed for the Study of Grain Boundaries and of Nitrided Cases : Grain Structures Revealed by Cutting." (Andrew Carnegie Research Report.)
- W. C. NEWELL : "The Estimation of Hydrogen in Steel and other Metals." (Paper No. 2/1940 of the Heterogeneity of Steel Ingots Committee (submitted by the Oxygen Sub-Committee).)
- O. A. SAUNDERS and H. FORD : "Heat Transfer in the Flow of Gas through a Bed of Solid Particles."

*Presentation of Papers.*

The following papers were presented for discussion :

- "Researches into the Structure of Alloys," by A. J. BRADLEY, F.R.S., W. L. BRAGG, F.R.S., and C. SYKES.
- "Manufacture of Pig Iron in America," by WM. A. HAVEN.

The Meeting then adjourned for lunch.

THURSDAY AFTERNOON.

The Meeting was resumed at 2.30 P.M. The PRESIDENT (Mr. John Craig) was in the Chair.

*Presentation of Papers.*

The following papers were presented for discussion :

- "Report on Corrosion Research Work at Cambridge University Interrupted by the Outbreak of War," by U. R. EVANS. (Paper No. 1/1940 of the Corrosion Committee.)
- "The Damping Capacity of Steel and Its Measurement," by G. P. CONTRACTOR and F. C. THOMPSON. (Paper No. 1/1940 of the Alloy Steels Research Committee.)
- "The Estimation of Hydrogen in Steel and other Metals," by W. C. NEWELL. (Paper No. 2/1940 of the Heterogeneity of Steel Ingots Committee (submitted by the Oxygen Sub-Committee).)

The Meeting adjourned at 5.15 P.M. until the following morning.



FRIDAY MORNING, MAY 3, 1940.

The Meeting was resumed at 10 A.M. The PRESIDENT (Mr. John Craig) occupied the Chair at first, but later, when he was called away, Dr. C. H. DESCH, F.R.S. (Vice-President), took his place.

*Presentation of Papers.*

The following papers were presented for discussion :

- "Anti-Piping Compounds and their Influence on Major Segregation in Steel Ingots," by E. GREGORY. (Paper No. 1/1940 of the Committee on the Heterogeneity of Steel Ingots.)
- "Heat Transfer in the Flow of Gas through the Interstices of a Bed of Solid Particles," by O. A. SAUNDERS and H. FORD.
- "Method of Sclero-grating Employed for the Study of Grain Boundaries and of Nitrided Cases: Grain Structures Revealed by Cutting," by Bo O. W. L. LJUNGGREN. (Andrew Carnegie Research Report.)

*Vote of Thanks.*

Mr. T. H. TURNER (Doncaster) said he was sure that all the Members would wish to thank the President for presiding the previous day and for the early part of that morning, and Dr. Desch for so ably stepping into the breach, as he had done on many other occasions, when the President had had to leave.

The CHAIRMAN (Dr. C. H. Desch, F.R.S.) acknowledged the vote of thanks briefly.

The proceedings then terminated.

FRIDAY AFTERNOON.

*Members' Luncheon.*

In the circumstances arising out of the outbreak of war, the Council had decided that the Annual Dinner of the Institute should not be held this year.

In its place arrangements were made for a Members' Luncheon to take place at Grosvenor House, Park Lane, London, W.1, on Friday, May 3, 1940, at 1 P.M. About six hundred members and their friends were present; among those who accepted invitations were: Sir William Bragg, O.M., K.B.E., F.R.S. (President of the Royal Society); Rear-Admiral B. A. Fraser, C.B., O.B.E. (Third Sea Lord and Controller of the Royal Navy); The Rt. Hon. Lord Austin of Longbridge, K.B.E. (President of the British Cast Iron Research Association); Colonel J. J. Llewellyn, C.B.E., M.P. (Parliamentary Secretary to the Minister of Supply); Captain R. S. Hilton (President of the British Iron and Steel Federation); Colonel Sir W. Charles Wright, Bt., K.B.E., C.B. (Controller of Iron and Steel); Mr. Ashley S. Ward (Master Cutler); Captain O. Lyttelton, D.S.O., M.C. (Controller of Non-Ferrous Metals); Sir James Lithgow,

M.C. (Controller of Merchant Shipping); Lieutenant-Colonel René Mayer; Lieutenant-General Sir J. Ronald E. Charles, K.C.B., C.M.G., D.S.O.; and the Presidents of many allied institutions.

The loyal toasts having been honoured, Sir WILLIAM BRAGG, O.M., K.B.E., F.R.S. (President of the Royal Society), proposed the toast of

*The Iron and Steel Institute*  
*and*  
*The Iron and Steel Industries.*

I have the honour to ask you, he said, to drink to the toast of The Iron and Steel Institute and The Iron and Steel Industries. I am glad of the opportunity to say a few words in admiration of the work which your Institute carries on to the advantage of this country. That advantage is at all times great; it is greater than ever in time of war.

War is a great revealer. Just as a flash of lightning on a dark evening lights up for us the whole landscape, showing hills and trees, houses and roads and a hundred details of which we had been barely aware, so war breaks in on a confused mass of beliefs, estimates and suppositions, and reveals for us the truth with startling clearness. It shows the mentalities of peoples, as, for example, the fundamental determination of France and Britain to have done with conditions which they can bear no longer; the strange degeneracy of Germany; the brilliant heroism of Finland; the lack of preparedness of some other nations; the hardening of Norway under a sudden and unprovoked attack.

With its sudden demand for combined and effective action by all members of a nation, war tests the strength of the links that bind those members together. If there are defects in our nation we find them out to our cost. Thus, we learnt in the last war, for example, the hindrances due to the presence of an ill-nourished and ill-educated section of the people, and take no little comfort from the fact that in this new war we are at least in much better case; we have begun to learn our lesson, though we do not yet know it by heart.

And, again, we were horrified to find, in 1914, how weak were the connections between the fighting forces, navy, army and air, on the one hand, and, on the other, the industrialists and scientists whose help was needed in order to meet the rapid changes and developments which the war demanded. Here, again, the lesson has not been forgotten.

The same is to be said of the supply of materials and tools. Many here well remember the strenuous and hurried steps that had to be taken to prepare the enormous number of gauges required for the rapid production of war material. As to material let me take a single example. We learnt with dismay of the lack of optical

glass in this country. Without it, observing instruments, range-finders, periscopes and the like could not be made. The deficiency is now remedied entirely. I have no doubt that others here present could add at great length to a list in which I have just given examples.

Yet there is one fundamental discovery—perhaps I should say one emphatic reassertion of a truth already dimly recognised—which is of first-class importance, and indeed includes in its scope many of those of which I have spoken already. It is the power of the knowledge of Nature's materials and laws. It is what is briefly described as "science."

I hesitate often to use the word "science," because it carries to so many minds a wrong significance. Think of it, if you please, in the simple terms I have used, the knowledge of Nature's materials and laws, and at once it is crystal clear that every activity of mankind which uses these materials and takes advantage of these laws—and what activity does not?—must surely take stock of them, try to understand them and learn how to use them. If we look, for example, at the industries of this country, we observe that every one of them is relying on science more and more. The newer the work, the more complete is the reliance. The two most recent activities, flying and communications by radio, are barely out of the laboratory, and their amazing progress would have been impossible without scientific research and the constant reference to scientific experiment. The huge electrical engineering industry has reached a greater maturity, and yet it is still a laboratory-fed enterprise. The ancient industries, metal-working, textiles, and so forth, have lately supplemented their traditional methods by recourse to fundamental experiment. It is to be recognised that such methods have in the course of ages furnished a marvellous technical skill, but there has been more development in the metal industry in, let us say, the last twenty-five years than in many preceding centuries.

The war drives home the lesson; so far as the actual busy preparations for war allow, research is more urgent than ever, though it may change in character from the longer to the shorter view. The physicists and chemists are snapped up for particular service in connection with the war. The success of a campaign may turn upon a scientific discovery or device, on the careful observance of knowledge gained by research.

When the Iron and Steel Institute takes in hand, with that vigour and good judgment which we cannot praise too highly, the research into those wide ranges of knowledge which relate to iron and steel, it gives a powerful urge in the right direction. We could wish indeed that its example were better followed. Science is yet far from its full application to all our activities. It has got to be clearly recognised, as it is not yet recognised, that science must be given its right place; we must not claim powers and uses which do not belong to it, but as to those which do rightly belong, they must be asserted again and again.

There are prejudices to be overcome. Some come from vested interests, but if these neglect science, they will in the end commit suicide. Much is due to mere ignorance. Again, the traditional education of this country has not realised in full the process of an inevitable change and has not yet shaped itself to meet it as it should. Some see in science the source of poison gas, bombs and other things of dread; they do not see that science used by ill-will must be met by science backed by good-will. And there is one more general objection, honourable though quite mistaken, voiced by many who strive to think right, that science leads to materialism, whereas the things of the spirit are the reality and our true care. It is a strange misunderstanding. It is a golden saying that man cannot live by bread alone; but it is also an iron fact that without bread man cannot live at all. An army, even if superb in its morale and training, would be useless without up-to-date weapons and material.

Science is just the study of Nature, of vast importance in its own sphere. It is not itself a moral principle; it is a body of knowledge which morality must use if it is to be effective.

The attitude of the thinking world to science is changing rapidly; the relations between industry and science are an obvious example of the change. The fine research work which the Iron and Steel Institute promotes in conjunction with the British Iron and Steel Federation is doing splendid service to the nation, quite apart from its influence on your own particular industry, and, as I said at the beginning of my short speech, I am glad of the opportunity of adding my testimony. Gentlemen, I give you the toast of The Iron and Steel Institute and The Iron and Steel Industries, coupled with the name of your Chairman, Mr. John Craig.

The PRESIDENT (Mr. John Craig, C.B.E.), who responded, said : A very great honour has been conferred on us to-day by the President of the Royal Society, Sir William Bragg, who has proposed the toast of our Institute. His presence has added lustre to our meeting and has given us an inspiration and an encouragement which are most helpful to all the Members, and we have listened with the keenest interest and pleasure to his remarkable address. (*Applause.*) The Institute owes a great deal to science. It has shown its progress in development when it has been most closely allied with scientific work; and when it has failed in any sections it has failed most frequently because it has not taken advantage of the knowledge that was at its disposal through the scientists. In the past the industrialists looked with a certain amount of fear upon the scientific men; they were afraid that if they introduced the scientist into business they might be in danger of being called upon to waste a great deal of money because his ideas were not fully matured, but only experimental, and so they neglected him; but I am glad to say that during my own lifetime the situation has changed, and



to-day the scientist holds an honoured place in all our deliberations, and we welcome all the knowledge that he places at our disposal.

Anyone present at our meeting yesterday morning, when Sir William's distinguished son, Professor Bragg, presented a paper, could not have failed to realise how important the scientists' work may be in unravelling some of the great problems that constantly confront the steelmaker; and we may have to look even to the pure scientists for the knowledge which shall solve some of the problems with which not only we but also the consumers of steel are confronted from day to day.

The making of steel is no easy matter. No man can walk through a melting shop and realise the possibilities of error that are there without recognising that a piece of perfect steel is the result of perfect work, and that the man who can produce it is to be honoured for his craftsmanship, knowledge and ability. And with the increasing demands for great speed and high power, the demands on the steel-maker are steadily growing. The standard of even twenty-five years ago is not to-day regarded as acceptable by many of our engineering friends, who have fresh problems confronting them and greater difficulties to overcome.

It is appropriate that Sir William Bragg, so distinguished a scientist, should come here and, in such generous terms, propose the toast of our Institute and our Industry. I can assure him that we are alive as we have never been before to the importance of research and to the work which is being done, day in and day out, not only in the works of the Members, but also in the Committees of the Institute. The research there is revealing solutions to some of the problems which baffled the pioneers of steelmaking. The money that is being spent on research represents one of the soundest investments that have been made by the industry.

I recognise that in the past it was perhaps a little difficult to overcome the reluctance of the workman to accept what he termed the "interference" of the scientist. But now the ordinary workman has a respect for the scientist such as he had not heretofore; and that is a demonstration—to use a phrase from Sir William's speech—of the power of knowledge. When the scientist walks into the melting shop or the mill and shows a man a better way to do a job, the man is always a sport and accepts the scientist's help.

I hope that this greater collaboration of science will continue to contribute to the usefulness of our industry. In the past there have been times when many employed in our industry felt that we were of no use and did not count in the economy of this great nation. We were neglected by the politician, despised by many others and looked upon as of no great national value. But now the situation has changed, and we are again regarded as being of some importance. I do hope that the industry will be able to contribute in greater and greater degree to the success of our nation in this critical time. I agree cordially with Sir William that this crisis has found us as an



industry in a position vastly different from that which we occupied in 1914, when many had to sit down and consider the erection of entirely new steelmaking plants; and that is not a thing we can do in a night. We are to-day in a more advanced stage of development and are better equipped to render national service than we were in 1914.

I thank Sir William for his presence here to-day. (*Applause.*) We are greatly encouraged by the fact that so distinguished a scientist has co-operated with us and by the tribute he has paid us, and I trust that the younger men who are scientists will feel that the industry has found a proper place for them. I am sure it is our experience that when the scientist takes his proper place the results are most encouraging.

I now have to propose the toast of

*Our Guests.*

I do so with very great pleasure. It is a source of great encouragement to be able to welcome so many distinguished gentlemen here, who by their presence acknowledge our position in the national life. We thank all the scientists who are here, and the heads of the great learned societies, and we thank all the Controllers who are here, because, after all, we are a controlled industry and it is only appropriate that they should look into the features of the men they are seeking to control! I have no doubt that, as they look upon us, they will realise that their task is not too difficult. We have been accustomed to control in the steelworks; if it was not control by a Controller, it was control by adversity! However, in a great struggle the obedience of those who are controlled is a necessary function.

We are glad to number among our guests Rear-Admiral Fraser. (*Applause.*) When he accepted my invitation I was particularly gratified. He holds a high office at the Admiralty, as Third Sea Lord and Controller of the Royal Navy; we honour him and the great Service he represents for the great work they have done and for the great work which we are confident they will yet do. (*Applause.*)

To all our guests we say that we are greatly encouraged by their presence here to-day. Amongst our guests are our Allies, and we give them a special welcome. (*Applause.*) I have had the pleasure of shaking hands also with a number of our steelmaking friends from other countries. Although I cannot describe them as "allies" officially, I am sure, from my knowledge of them, that they are allies at heart. We welcome them here to-day. (*Applause.*)

I ask our Members to rise and join with me in drinking cordially to our Guests, and I couple with the toast the name of Rear-Admiral Fraser. (*Applause.*)

Rear-Admiral (now Vice-Admiral) B. A. FRASER, C.B., O.B.E. (Third Sea Lord and Controller of the Royal Navy), responding on

behalf of the Guests, said : When I came here I was not quite certain whether I should have to commence my remarks by addressing you as "men of iron and steel," but on looking up my old textbooks I found that iron is generally associated with other ingredients and that pure iron is a curiosity, and so I came to the conclusion that you must be either impure or curiosities ! (*Laughter.*) It would be impertinent for me, of course, to suggest which characteristic you might prefer !

I have the honour to respond to-day for very many distinguished guests ; and it is a particularly great honour to be able to include among them our Allies, whom we are so glad to welcome. (*Applause.*)

Looking along the table, I am sure that I have never before in my life seen so many Controllers ! They do not all appear to be in adversity. But it occurs to me that this is the one opportunity I have of talking without giving them the chance to reply. (*Laughter.*) I feel that I should like to say what I think some of my colleagues here might have said if they were responding. We have with us Colonel Llewellyn, the Parliamentary Secretary to the Minister of Supply. Of course, he is full of impurities ; he is a Colonel in the Army, and a deserter from the Navy. (*Laughter.*) All I can say is that our loss is exceeded only by the great gain of the Ministry of Supply. (*Applause.*) I know that if he had been able to say a word to-day he would have said that the Admiralty steel quota which he endeavoured to cut last week would be reinstated to-morrow ! I know that he will have no reply to that ! (*Laughter.*)

Then there is Colonel Sir Charles Wright, a Past-President of your Institute, and now Controller of Iron and Steel. I am sure that if he were speaking he would say that he has a hell of a job, but that he can always smile. That is the only attitude to adopt in these circumstances.

We have with us also Mr. Ashley Ward, the Master Cutler, whose character, of course, must be stainless ! I know he would say that he was going to double my gun mounting supply by the end of next month, and I am sure that that is what he is trying to do.

My immediate neighbour at the table to-day is Captain Lyttelton, the Controller of Non-Ferrous Metals, whom I have never yet found to be rusty in any degree ! There is a saying "Spare the rod and spoil the child," but I can assure you that he beats me with copper rod about once a week. (*Laughter.*)

I feel that if I continue to refer to my fellow guests I shall need all the industry's production of armour-plate around me ! However, I should like to say a word or two about the Royal Navy. As you know, these are disappointing times. It is essential that we and the country should ensure that we are quicker off the mark, on both the civilian side and the Service side. We in the Navy have to fight, not only the enemy, but also the elements. From the Naval point of view I can assure you that we have our disappointments. But the Navy is in no way down-hearted, and it never will

be down-hearted. (*Applause.*) The other day I had the opportunity to talk to the Captain of H.M.S. *Renown*, who went into action against a German battle cruiser recently, and he told me that as soon as he opened fire the German battle cruiser fled. From the Naval point of view we are quite sure that when the German is faced with something near equality of strength he will not meet it.

The Captain of H.M.S. *Warspite*, who holds the V.C., is rather a big man and has a large beard. I asked him whether he had his beard singed in the recent famous action; he told me that it was not singed, but that it was useful for keeping the snow off! He also told me that German aircraft would not come near when the ships opened fire. The difficulty is, of course, that at sea the conditions change so much and so frequently; sometimes there are low clouds and a ship is liable to be surprised, so that it might be damaged occasionally. The damage so far has been about what we expected it might be.

I should like to pay tribute to the Fleet Air Arm and to our little anti-aircraft ships which have been doing such noble work in support of the Army. (*Applause.*) The Fleet Air Arm is a comparatively small body of men. Their machines must be inferior to those of our sister Service, because of the limitations of ship work. But that is counterbalanced by the very high skill of the pilots and observers, who have been trained very intensely over a period of several years; they have worked very hard and they are skilled in navigation, and during the last week or so each pilot has flown two or three times each day. Sometimes they have maintained contact with the enemy until they have run out of petrol and have been forced down. In most cases we have been able to recover the crews, and the first thing the pilots and observers do when they get back is to ask for their next machine to take off. A young midshipman pilot in one of our machines recently ran out of fuel; he landed on a ground where nobody else thought he could land, he scrounged some petrol, took off again and returned to his work.

Our little anti-aircraft ships have had a very difficult time; they have been attacked continuously, so that the crews have been at action stations all day; they have destroyed quite a number of enemy machines, and only after several days in action, using up all their ammunition, have they been damaged or sunk, as the case may be. When the little *Bittern* was sunk she had been fighting hard all day, and her ammunition had practically gone when she was at last hit. Something like 150 bombs had been dropped around her, and at last one found its mark. A bomb went through the forecastle of another little ship and caused casualties. The behaviour of the officers and men was magnificent; they dealt with the damage, and got the ship home. She is now under repair, and will shortly go back into action. (*Applause.*)

Before I conclude, I should like to mention one other of your guests, Sir James Lithgow, the Controller of Merchant Shipping.

(*Applause.*) He is a colleague of mine, and at the Admiralty we have welcomed most warmly his help and advice and experience. When he came to the Admiralty I think he felt that every Naval Officer was entirely unprincipled about what was wanted; nevertheless, I have to keep my weather eye on him sometimes! (*Laughter.*)

On behalf of the Guests I should like to thank your President for his kind words to us, and to express again our appreciation of your very kind hospitality to us. (*Applause.*)





## REPORT OF COUNCIL.

THE Annual Report of the proceedings and work of the Iron and Steel Institute during the year 1939 is submitted by the Council for the approval of Members at this, the Seventy-First Annual General Meeting. For the convenience of Members some sections of this Report include information up to April, 1940.

The outbreak of war has so far had comparatively little effect on the normal activities of the Institute, with the exception that the Autumn Meeting, arranged to be held in Cardiff, had to be cancelled, and that the issue of a monthly Journal, proposed from January, 1940, has been postponed. The Council have given permission for war work to be undertaken, provided that this is not detrimental to the ordinary work of the Institute, which is of importance to Members and to the iron and steel and associated industries in war-time. Some of the junior members of the staff have been called up for military service. The research activities of the Institute in conjunction with the Iron and Steel Industrial Research Council have assumed an additional importance and are being actively prosecuted.

### ROLL OF THE INSTITUTE.

The membership of the Institute at the 31st December, 1939, was two thousand seven hundred and four, an increase of seventy-four during the year.

The details of the membership compared with those of a year ago are as follows :

	31/12/'38.	31/12/'39.
Patron . . . . .	1	1
Honorary Members . . . . .	13	15
Life Members . . . . .	69	68
Ordinary Members . . . . .	2341	2407
Associates . . . . .	206	213
	<hr/>	<hr/>
	<u>2630</u>	<u>2704</u>

The total membership figures for 1938 and 1939 include eight members whose names are retained in the List of Members in an honorary capacity by order of the Council.

Variations in the membership since the formation of the Institute in 1869 are shown in Fig. 1.

During the year one hundred and eighty-one new Members and thirty-nine new Associates were elected. These included sixty-seven

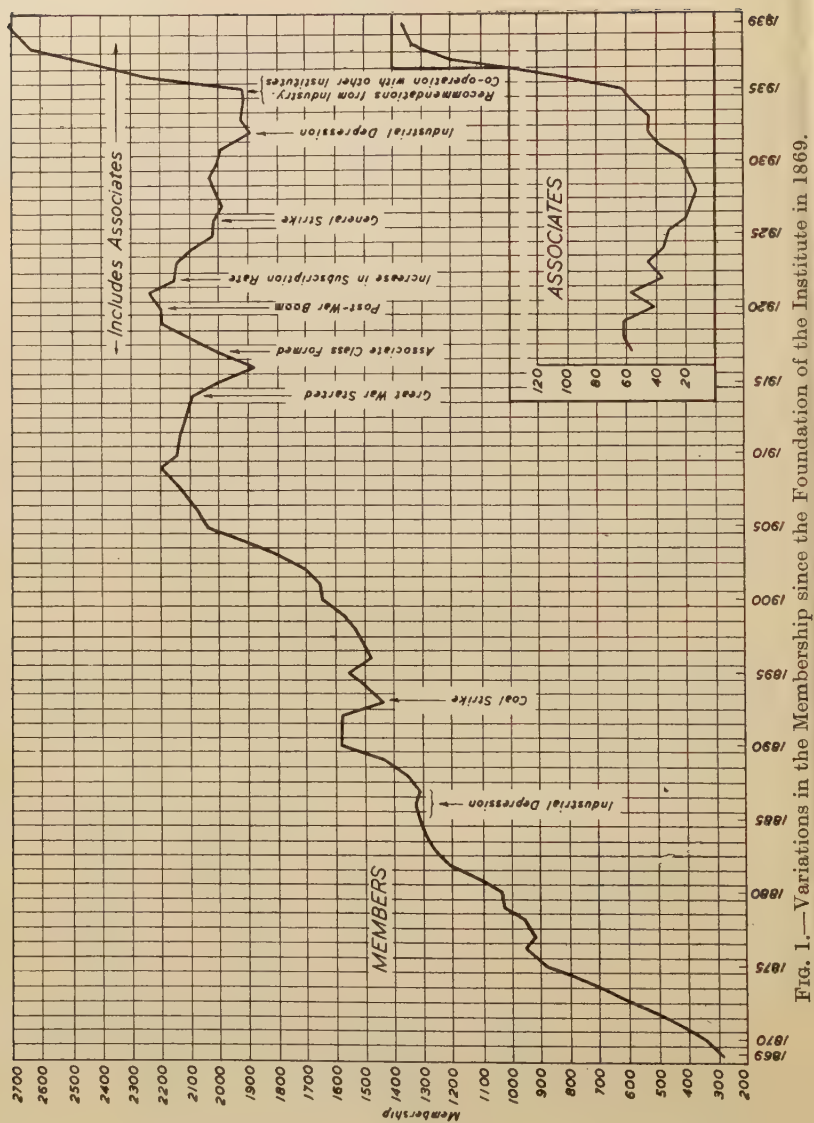


Fig. 1.—Variations in the Membership since the Foundation of the Institute in 1869

Members and eleven Associates nominated by Companies which subscribed to the Special Subscription Fund and forty Members and thirteen Associates who joined under the scheme of co-operation with the Institute of Metals; four Associates were elected under the special arrangement made with the American Institute of Mining and Metallurgical Engineers, and two under the arrangement with Jernkontoret. Twenty-eight Associates were transferred to Membership and ten former Members were reinstated. Seventy-eight Members and two Associates resigned and the deaths of forty-two Members were reported.

The membership was greater than on any previous occasion, and the increase in the Membership, both of full Members and of Associates, is satisfactory. The Council consider that there is no reason why this level should not be maintained, although a considerable falling off in the non-British membership must be anticipated as a result of the war. The Council believe, however, that there are still many officials in the iron and steel and associated industries, as well as individuals interested in ferrous metallurgy, to whom membership would be advantageous, and they hope that those who are in a position to do so will give them every encouragement to join the Institute.

#### OBITUARY.

The Council regret to record the deaths of the following forty-four Members which occurred during the year 1939 :

ARRILUCE DE IBARRA, Marques de (Bilbao, Spain)	?
BARNES, E. J. (Sheffield)	September 18th.
BAYNES, Dr. CHARLES (Llandudno Junction)	January 16th.
BENNETT, BENJAMIN (Rotherham)	October 9th.
BENTHAM, FREDERICK LISLE (Middlesbrough)	?
BOND, GEORGE CRESWELL (Nottingham)	July 17th.
BOYLSTON, H. M. (Cleveland, Ohio)	July 28th.
BRANDT, Captain BORIS (Richmond, Surrey)	October 30th.
BREARLEY, HORACE (Rotherham)	May 18th.
BRONIEWSKI, Professor Dr. W. (Warsaw, Poland)	February 13th.
CORRIE, J. B. (London)	March 3rd.
COGHLAN, C. ST. JOHN (Leeds)	October 27th.
CRANE, CHARLES RICHARD (Chicago, Ill.)	February.
DAVIDSON, JAMES (Cardiff)	October 30th.
DREUX, A. (Mont St. Martin, France) (Hon. Vice-President)	April 15th.
ECHEVARRIA, LUIS DE (Bilbao, Spain)	?



FAY, Dr. HENRY (Brookline, Mass.)	April.
FIRTH, WYBERT (Consett)	May 17th.
FLETCHER, JOSEPH ERNST (Dudley)	November 30th.
GERMEAU, EUGÈNE (Clabecq, Belgium)	December 12th.
GLOVER, Major R. B. (Mossley, Lancs.)	October.
GRAY, JAMES H. (Berkeley, Cal.)	January 13th.
HILL, KENNETH (London)	February 7th.
HILL, WILLIAM (Malvern)	March 29th.
HOLLAND, BERNARD AUGUSTUS (London)	November 20th.
IRONS, R. H. (Harrisburg, Pa.)	January 5th.
LANTSBERRY, F. C. A. H. (New York)	June 29th.
LOUIS, Professor HENRY (Newcastle-on-Tyne) (Past-President)	February 22nd.
MACKENZIE, KENNETH D. (Glasgow)	May 8th.
MARSDEN, WALTER (New Barnet)	June 18th.
MORRIS, W. TUDOR (Swansea)	March 5th.
NEEDHAM, Colonel J. G. (Manchester)	September 11th.
ODELBERG, ERNST (Djursholm, Sweden)	February 9th.
ORUETA Y RIVERO, J. DE (Renteria, Spain)	?
PHILLIPS, FRANCIS ROSSER (Swansea)	July 2nd.
RICARDO DE ZUBIRIA, J. (Bilbao, Spain)	?
RUSSELL, WILLIAM COLIN (Burgess Hill, Sussex)	February 21st.
SAUVEUR, Professor ALBERT (Cambridge, Mass.)	January 26th.
SCHWAB, CHARLES M. (New York) (Hon. Vice-President)	September 18th.
THOMAS, F. MORETON (Sheffield)	January 21st.
VILLA ONAINDIA, J. IGNACIO (Spain)	?
WHEELER, Professor R. V. (Sheffield)	October 28th.
WILLIAMSON, RICHARD (Workington)	April 9th.
WRIGHT, A. LESLIE (Derby)	September 4th.

The deaths of the following three Members took place earlier than 1939, but were not previously reported :

MOND, EMILE (London)	December 30th, 1938.
STEPHENS, Sir ALFRED (Kidwelly, Carmarthenshire)	November 28th, 1938.
WALTON, ERNEST (Middlesbrough)	September, 1938.

Professor Louis, Monsieur Dreux and Mr. Schwab had all had very long associations with the Institute, having taken up membership in 1881, 1889 and 1895, respectively. Professor Louis, who, like Mr. Schwab, was a Bessemer Gold Medallist, was President for the term 1929-31, while Monsieur Dreux and Mr. Schwab—two of the best-known members of the steel industries of France and the United States of America—were Honorary Vice-Presidents. Professor Sauveur, another Bessemer Gold Medallist, and Professor

Boylston were American scientists of world-wide fame, who had contributed much to the literature of the subjects which they studied. Professor Broniewski was a well-known Polish metallurgist, who played a large part in the public service of his country. Professor Wheeler's work on fuel technology and particularly on combustion, with special reference to the causes and prevention of explosions in coal mines, had gained him an international reputation. Mr. Mond received high honours at the hands of the French and Belgian Governments during the war of 1914-18, and later he founded the Francis Mond professorship of aeronautical engineering at Cambridge in memory of his son who was killed in 1918. Mr. Odelberg was well known in the Swedish mining industry, his services to which gained for him the Jernkontoret Gold Medal in 1925. Mr. Fletcher's contributions to the knowledge of the founding and properties of cast iron were of great benefit to the foundryman. Colonel Needham was a familiar figure on the Manchester Royal Exchange and the Birmingham Exchange.

#### FINANCE.

*(The Statement of Accounts for 1939 is attached to this Report.)*

The accounts for 1939 differ from those for 1938 mainly in that donations to the House Fund and Industrial Subscriptions, resulting from the appeal made last year, have been included. Further reference to the appeal is made in another section of this Report.

#### *General Fund.—Balance Sheet.*

Additional expenditure at No. 4 Grosvenor Gardens amounted to £487, of which £327 was for air-raid precautions; £13,684 was brought forward from last year, making a total expenditure on this account of £14,171. Against this has been set the sum of £13,033, being the donations to the House Fund received before the end of the year; the balance of £1,138 has been included among the assets.

The overdraft at the Institute's bankers, which last year was £9,710, has been paid off, and cash at bank and in hand has increased from £148 to £517.

Excess of expenditure over income during the year (£228) and the net cost of the Symposium on Steelmaking held in 1938 (£863) have been charged against the reserve account. Expenditure on the Symposium included the cost of publishing the proceedings, and it should be recorded that over 1,500 copies of this important publication, which is the most comprehensive and up-to-date account of British steelmaking practice, were distributed free of charge to Members. As usual, entrance fees have not been included in the year's income, and an addition has been made to the reserve for the ten-year index; as a result the Suspense Account is £327 greater than last year.

The remaining items of the Balance Sheet do not appear to require comment.

*General Fund.—Income and Expenditure Account.*

Both expenditure and income have increased. Expenditure at £18,279 was £2,472 greater than last year and £228 in excess of income. The increased expenditure was due to two main causes—first to the increase in membership and in service rendered to Members, and secondly to the expenditure directly resulting from the occupation of the new offices at No. 4 Grosvenor Gardens. These offices were first occupied in June, 1938, so that accounts for that year included the cost of the Institute's larger and more expensive premises for six months only. The first of these heads (including such items as Salaries, National Insurance, Staff Superannuation Fund, Publishing Expenses, Stationery, Postage and Travelling) cost £1,508 more than last year. The expenditure directly resulting from the occupation of the new offices at No. 4 Grosvenor Gardens (including Rent, Repairs, Cleaning, Heating, &c., Furniture and Insurance) was increased by £828. Various items of income have also increased. The sum payable by the Institute of Metals was £1,100 instead of £550; subscriptions have increased from £6,709 to £6,829, and sales of publications from £1,532 to £1,763; gross contributions from the Industry to the Special Subscriptions Fund were £4,166 instead of £2,853, and net subscriptions after making the usual transfers to reserve were £3,877 instead of £2,632. The account again shows how essential these Industrial Subscriptions are if the Institute is to maintain the service which it renders to Members and to the industry. The only other item requiring special mention is the expenditure on the Autumn Meeting of £162. For two years running the political situation has made it necessary to cancel the Autumn Meeting, and on both occasions the registration fees have been refunded to Members in full, although considerable preliminary expenditure had been incurred.

*Trust Funds.*

The accounts of the Williams Prize Fund and the Andrew Carnegie Research Fund are shown in the ordinary way, and both accounts show substantial balances of income over expenditure.

*Investments.*

The outbreak of war resulted in a general depreciation in the value of securities, and especially of gilt-edged securities such as are held by the Institute. Nevertheless the market value at 31st December, 1939, exceeded the cost value at which they are included in the balance sheets by £2,755. The figures are as follows: Nominal

value, £67,508; cost value as shown on Balance Sheet of the Institute, the Williams Prize Fund and the Andrew Carnegie Research Fund, £56,191; market value at 31st December, 1939, £58,946.

### HOUSE FUND AND INDUSTRIAL SUBSCRIPTIONS.

At the Annual Meeting in 1939 the President launched an appeal to Companies and Associations in the iron and steel and connected industries with the object of raising the sum of £15,000 for a House Fund to pay the cost incurred in moving into the new offices and of obtaining subscriptions of not less than £4,000 a year for a period of seven years. This sum is necessary if the services which the Institute renders to the industry are to be maintained without diminution. The Council are gratified at the success of this appeal. As the accounts show, over £13,000 has been contributed to the House Fund and subscriptions of nearly £3,300 have been received. Companies were asked to sign a covenant undertaking to pay their subscriptions for a period of not less than seven years, so that the Institute might claim a refund of income tax. Most subscribing Companies have agreed to do this, and as a result the Institute has benefited by an additional sum of £874.

A number of Companies in the industries served by the Institute have not yet responded to the Appeal, but the Council hope that these will do so in the immediate future, so that the amounts of the original appeal may be obtained. They venture to suggest that it is equitable that the cost of maintaining a central organisation such as the Institute should be shared by the whole industry.

The Council wish to express their grateful thanks to all Companies and Associations which have contributed to the appeal, as well as to the President, Lord Dudley, and all others who have personally interested themselves in its success.

The following is a list of those Companies from which subscriptions were received during the year under review :

C. Akkrill & Co., Ltd.  
Edgar Allen & Co., Ltd.  
Babcock and Wilcox, Ltd.  
Baldwins, Ltd.  
Arthur Balfour & Co., Ltd.  
Frederick Braby & Co., Ltd.  
Briton Ferry Steel Co., Ltd.  
Broken Hill Proprietary Co., Ltd.  
Burnell & Co., Ltd.  
Butterley Co., Ltd.  
Bynea Steel Works, Ltd.  
Colvilles, Ltd. (including Wm. Beardmore & Co., Ltd.).  
Consett Iron Co., Ltd.  
Darwen and Mostyn Iron Co., Ltd.



Dorman, Long & Co., Ltd.  
Thos. Firth and John Brown, Ltd.  
General Refractories, Ltd.  
Gjers Mills & Co., Ltd.  
M. and W. Grazebrook, Ltd.  
Guest Keen Baldwins Iron and Steel Co., Ltd.  
Guest Keen and Nettlefolds, Ltd.  
J. J. Habershon & Sons, Ltd.  
Hadfields, Ltd.  
High Speed Steel Alloys, Ltd.  
N. Hingley & Sons, Ltd.  
Wm. Jessop & Sons, Ltd.  
Richard Johnson & Nephew, Ltd.  
Lancashire Steel Corporation, Ltd.  
Lamberton & Co., Ltd.  
Arthur Lee & Sons, Ltd.  
John Lysaght, Ltd.  
Millom and Askam Hematite Iron Co., Ltd.  
Mond Nickel Co., Ltd.  
Neepsend Steel and Tool Corporation.  
Newton Chambers & Co., Ltd.  
Samuel Osborn & Co., Ltd.  
Oughtibridge Silica Firebrick Co., Ltd.  
Park Gate Iron and Steel Co., Ltd.  
Thomas Perry & Sons, Ltd.  
Round Oak Steel Works, Ltd.  
Simon-Carves, Ltd.  
Walter Somers, Ltd.  
South Durham Steel and Iron Co., Ltd.  
Stanton Ironworks Co., Ltd.  
Steetley Lime and Basic Co., Ltd.  
Stewarts and Lloyds, Ltd.  
John Summers & Sons, Ltd.  
Tata, Ltd.  
R. B. Tennent, Ltd.  
Richard Thomas & Co., Ltd.  
United Steel Companies, Ltd.  
Upper Forest and Worcester Steel and Tinplate Works, Ltd.  
Vickers, Ltd.  
Wellman Smith Owen Engineering Corporation, Ltd.  
Whitehead Iron and Steel Co., Ltd.  
Woodall-Duckham Vertical Retort and Oven Construction Co. (1920), Ltd.

The following Association has contributed to the appeal since 31st December, 1939 :

South Wales Siemens Steel Association.

## CHANGES ON THE COUNCIL.

During the year the following changes on the Council were made: Mr. John Craig, C.B.E. (Vice-President), was elected President-Elect. Sir Edward J. George (Vice-President) and Mr. John E. James (Member of Council) were nominated Honorary Vice-Presidents. Mr. J. Sinclair Kerr and Mr. C. J. Walsh were elected Members of Council.

Mr. L. F. Wright became an Honorary Member of Council on succeeding Mr. A. Scholes as President of the Cleveland Institution of Engineers, and Mr. G. R. Bashforth became an Honorary Member of Council on succeeding Mr. W. H. Lewis as President of the Staffordshire Iron and Steel Institute.

During the year the President of the Newport and District Metallurgical Society, and as from the 1st January, 1940, the President of the Swansea Technical College Metallurgical Society, were nominated Honorary Members of Council. Mr. G. H. Latham, President of the Newport Society, and Mr. O. J. Thomas, President of the Swansea Society, accepted invitations to become Honorary Members of Council during their terms of office.

In accordance with Bye-Law 10, the names of the following Vice-Presidents and Members of Council were announced as being due to retire at the Annual Meeting in 1940:

*Vice-Presidents*: Sir William Larke, K.B.E.; Mr. A. O. Peech; Dr. C. H. Desch, F.R.S.

*Members of Council*: Mr. E. J. Fox; Dr. T. Swinden; Dr. A. McCance; Mr. P. B. Brown; Mr. J. R. Menzies-Wilson.

No other Members having been nominated up to one month previous to the Annual Meeting the retiring Members are presented for re-election.

## HONOURS CONFERRED ON MEMBERS.

The Council offer warm congratulations to Members of the Institute on honours and appointments received during 1939.

The Right Hon. the Earl of Dudley, M.C., was appointed Commissioner for Civil Defence for the Midlands.

Sir W. Peter Rylands, J.P., was created a Baronet and Mr. Edward J. George a Knight Bachelor. Engineer Vice-Admiral Sir Harold Brown was made a G.B.E. (Military Division) and Mr. R. Crichton a C.B.E. Major H. H. Jackson, M.C., J.P., was a recipient of the O.B.E. The Honorary Freedom of the Borough of Swansea was conferred on the Right Hon. Lord McGowan of Ardeer, K.B.E., and the Honorary Freedom of the City of Sheffield on Sir Robert Hadfield, Bt., D.Sc., D.Met., F.R.S., and Mr. H. Brearley. Mr. G. Summers, D.L., was elected High Sheriff of Flintshire; Mr. G. H. Latham, Mr. Lewis Jones, M.P., and Colonel

H. B. Sankey were made Justices of the Peace for Newport, Mon., Swansea and the County of Stafford, respectively.

Professor L. Guillet and Mr. P. Chevenard were appointed Grand Officer and Officer, respectively, of the Legion of Honour. Dr. Z. Jeffries was elected a Member of the National Academy of Sciences and an Honorary Member of the American Society for Metals. Engineer Vice-Admiral Sir Harold Brown was elected an Honorary Life Member of the Institution of Mechanical Engineers, Professor Thomas Turner a Fellow of the Imperial College of Science and Technology, and Lord Dudley an Honorary Member of the Chemical and Mining Society of South Africa for the year ending June 30th, 1940.

The Henry Marion Howe Medal was presented to Dr. F. R. Mehl, the Captain Robert Dollar Award to Mr. J. A. Farrell, and the Robert Woolston Hunt Award of the American Institute of Mining and Metallurgical Engineers to Dr. J. Chipman. Sir Harold Carpenter, F.R.S., was awarded the Medal of the Institute of Metals, Dr. H. A. Schwartz the E. J. Fox Gold Medal of the Institute of British Foundrymen and Mr. J. G. Pearce the Oliver Stubbs Gold Medal of the same Institute, Dr. S. F. Dorey the M. C. James Gold Medal of the North-East Coast Institution of Engineers and Shipbuilders, and Mr. V. Delpont the Gold Medal of the Association Technique de Fonderie. Professor K. Honda was the first to receive the Gold Medal of the Japanese Institute of Metals named after himself. The Silver Medal of the Junior Institution of Engineers was presented to Mr. R. Lowe.

On Mr. J. E. Hurst was conferred the honorary degree of D.Met. (Sheffield), and on Sir Andrew Duncan, G.B.E., and Mr. J. Ward, J.P., the honorary degree of LL.D. (Glasgow and Sheffield, respectively).

Mr. J. P. Gill was elected President of the American Society for Metals, Captain R. S. Hilton President of the British Iron and Steel Federation for 1939, Dr. W. H. Hatfield, F.R.S., President of the British Cast Iron Research Association, Professor F. C. Lea Vice-President of the Institution of Mechanical Engineers, Professor J. H. Andrew President of the Institute of Vitreous Enamellers, and Mr. Malcolm Brown President of the Sheffield Section of the Institute of British Foundrymen.

Dr. H. J. Gough, M.B.E., F.R.S., became a Member of Council of the Royal Society. Mr. S. Willis was re-elected President and Mr. C. Laycock was made a Senior Vice-President of the Sheffield Chamber of Commerce. Mr. A. S. Ward was elected Master Cutler and the Hon. Robert A. Balfour Senior Warden of the Cutlers' Company in Hallamshire. Mr. W. B. Pickering became a Member of Committee A of the Midland District Committees of Investigation. Sir Harold Carpenter, F.R.S., was elected Chairman of the Joint Committee on Materials and their Testing, and Mr. L. Taverner was appointed Director of the Government of South Africa Mineral

Research Laboratory and Professor of Metallurgy at Witwatersrand University. Professor R. S. Hutton was elected Chairman of the Council of the City and Guilds of London Institute. Mr. J. S. Whitmore was appointed Chairman of the Newport Harbour Commissioners, and Captain H. Leighton Davies Vice-Chairman of the Welsh Tinplate Pool.

#### BESSEMER GOLD MEDAL.

The Bessemer Gold Medal for 1939 was awarded to Mr. James Henderson in recognition of his valuable contributions to, and life-long encouragement of, technical and scientific development in the industry.

The Council have decided to award the Bessemer Gold Medal for 1940 to Dr. Andrew McCance in recognition of his eminence in the application of science to the iron and steel industry.

#### ANDREW CARNEGIE SILVER MEDAL.

The Andrew Carnegie Silver Medal for 1939 was awarded to Mr. O. W. L. Ljunggren for his paper on "Method of Sclero-grating Employed for the Study of Grain Boundaries and of Nitrided Cases; Grain Structures Revealed by Cutting." The memoir is published in the present volume of the *Journal of the Iron and Steel Institute*.

#### WILLIAMS PRIZE.

The Williams Prize for 1939 was awarded jointly to Mr. W. B. Lawrie for his paper on "The Refining of Metal in the Basic Open-Hearth Furnace. The Influence of Fluorspar on the Process," and to Mr. W. T. Wilson for his paper on "The Rolling of Sections at the Appleby-Frodingham Steel Company, Limited." Both of these papers appeared in the No. I. volume of the *Journal of the Iron and Steel Institute* for 1939.

#### ABLETT PRIZE.

The Ablett Prize for 1939 was awarded to Mr. H. Escher for his paper on "Ten Years' Development in Steam Engineering at the Port Kembla Steelworks, N.S.W., Australia," which was published in the No. I. volume of the *Journal of the Iron and Steel Institute* for 1939.

The Council have gratefully accepted the offer of Captain C. A. Ablett, O.B.E., B.Sc., M.Inst.C.E., Managing Director of the Cooper Roller Bearings Co., Ltd., to renew his Prize for 1941. The Prize, of £50, is awarded for the paper which, in the opinion of the Council, is the best paper on a subject connected with engineering in iron or

steel works, written by a junior engineer, whether or not he is a Member of the Institute, the conditions being that the author of the paper shall be a British subject and that at the time of presenting the paper he shall be employed in an iron or steel works in Great Britain or the British Empire, that he is under 35 years of age and that he holds a position not higher than that of a Departmental Engineer.

#### ANDREW CARNEGIE RESEARCH SCHOLARSHIPS.

Grants were made by the Council in 1939 to the following candidates :

G. PARKER (The University, Leeds).—£100 in aid of a research on the determination of oxygen in steel (second grant).

A. LATIN (Department of Metallurgy, Manchester University).—£100 for a critical review of existing knowledge concerning the structure of ingots.

(The above researches are being carried out on behalf of the Joint Research Committees of the Iron and Steel Industrial Research Council and the Institute.)

O. GESSNER (Breslau, Germany).—£100 in aid of a research on the viscosity of cast-iron alloys, steels, metals and alloys and slags (second grant).

B. LJUNGGREN (Stockholm, Sweden).—£100 in aid of a microsclerometric investigation of grain boundaries (second grant).

F. L. GILLEMOT (Mechanical Technological Institute, Budapest, Hungary).—£100 in aid of a research on the influence of the base material and manufacturing procedure on the fatigue of wire ropes.

T. P. HOAR (Metallurgical Laboratories, Cambridge University).—£100 for a study of the conditions leading to intensive corrosion.

#### THE WORSHIPFUL COMPANY OF BLACKSMITHS.

No recommendation for admission to the Worshipful Company of Blacksmiths was made for the year 1939.

#### MEETINGS.

##### *Annual Meeting.*

The Annual Meeting of the Institute was held on Wednesday, Thursday and Friday, 3rd, 4th and 5th May, 1939; the Right Honourable the Earl of Dudley, M.C., President, was in the Chair. In addition to a number of papers from individual authors, three Special Reports were presented and discussed.

##### *Annual Dinner.*

The Annual Dinner was held on Thursday, 4th May, 1939, at Grosvenor House, Park Lane, London, W.1; the attendance



numbered eight hundred and forty Members and Guests, a record. The following proposed or replied to toasts :

The Right Hon. Lord Chatfield of Ditchling, G.C.B., K.C.M.G., C.V.O. (Minister for Co-ordination of Defence).

The Right Hon. the Earl of Dudley, M.C. (President).

The Right Hon. the Viscount Greenwood of Holbourne, P.C., K.C.

The Right Hon. Richard B. Bennett, P.C.

Monsieur Léon Greiner (Honorary Vice-President).

Engineer Vice-Admiral Sir Harold A. Brown, K.C.B. (Director-General of Munitions Production).

### *Autumn Meeting.*

The Autumn Meeting was held on Thursday, 23rd November, 1939, at 3.30 P.M., at the Offices of the Institute, 4 Grosvenor Gardens, London, S.W.1. In the unavoidable absence of the President, Lord Dudley, Mr. James Henderson (Honorary Treasurer) was in the Chair. No papers were presented for discussion and formal business only was transacted.

### *Proposed Autumn Meeting in Cardiff.*

Arrangements had been made for the Autumn Meeting to be held in Cardiff, with visits to works at Ebbw Vale and Newport, on 12th to 15th September, but the Meeting was cancelled on the outbreak of war. Six hundred and sixty-four Members and Ladies had expressed their intention of attending.

The Council wish to thank Mr. J. S. Hollings (Vice-President), the Chairman, Mr. W. F. Cartwright, the Honorary Secretary, Mr. C. A. Young, the Honorary Treasurer, and the Members of the Local Executive Committee, as well as The Right Worshipful the Lord Mayor of Cardiff and the City Authorities, the President and Council of the South Wales Institute of Engineers, the owners of works in the Iron and Steel Industries of Cardiff, Newport and Ebbw Vale, and all those who assisted in making the arrangements for the Meeting.

### *Joint Meetings.*

(For the period from 31st March, 1939, to 30th April, 1940.)

During the autumn and winter months the following joint meetings were held with the Societies named :

#### **Saturday, 2nd December, 1939 : The Ebbw Vale Metallurgical Society.**

*Place and Time :* Christ Church Hall, Ebbw Vale, at 4 P.M.

*Chairman :* Mr. Arthur Woodward, Chairman of the Ebbw Vale Metallurgical Society.

*Paper :*

“ The Causes of Roll Marks on Tinplate,” by Mr. Roosevelt Griffiths.

**Saturday, 9th December, 1939 : The Cleveland Institution of Engineers.**

*Place and Time* : Cleveland Scientific and Technical Institute, Corporation Road, Middlesbrough, at 2.0 P.M.

*Chairman* : Mr. L. F. Wright, President of the Cleveland Institution of Engineers.

*Paper* :

“Ten Years’ Development in Steam Engineering at the Port Kembla Steelworks, N.S.W., Australia,” by Mr. H. Escher. (The paper was presented by Mr. A. F. Webber.)

**Tuesday, 23rd January, 1940 : The Lincolnshire Iron and Steel Institute,**

*Place and Time* : The Modern School, Cole Street, Scunthorpe, at 7.30 P.M.

*Chairman* : Mr. N. Nisbet, President of the Lincolnshire Iron and Steel Institute.

*Paper* :

“Ten Years’ Development in Steam Engineering at the Port Kembla Steelworks, N.S.W., Australia,” by Mr. H. Escher. (The paper was presented by Mr. A. F. Webber.)

**Tuesday, 20th February, 1940 : The Sheffield Society of Engineers and Metallurgists and the Sheffield Metallurgical Association.**

*Place and Time* : The Grand Hotel, Sheffield, at 7.30 P.M.

*Chairman* : Dr. W. H. Hatfield, F.R.S., Vice-President of the Iron and Steel Institute.

*Papers* :

“Oxygen Determinations on a Series of Bath Samples Taken from an Acid Open-Hearth Furnace (Cast B14473),” by Dr. G. E. A. Bramley, Dr. W. R. Madocks and Mr. G. Tateson. (This paper formed Section III. of the Eighth Report on the Heterogeneity of Steel Ingots (*Special Report No. 25*).)

“Tensional Effects of Torsional Overstrain in Mild Steel,” by Professor H. W. Swift.

“A Study of a Nickel-Chromium-Molybdenum-Vanadium Steel Ingot,” by Dr. W. H. Hatfield, F.R.S. (This paper formed Section V. of the Eighth Report on the Heterogeneity of Steel Ingots (*Special Report No. 25*).)

**Tuesday, 12th March, 1940 : The Staffordshire Iron and Steel Institute.**

*Place and Time* : The Midland Hotel, Birmingham, at 6.45 P.M.

*Chairman* : Mr. G. R. Bashforth, President of the Staffordshire Iron and Steel Institute.

*Papers* :

“A Study of ‘Strain-Age-Hardening’ of Mild Steel,” by Principal C. A. Edwards, F.R.S., Mr. N. H. Jones and Mr. B. Walters.

“The Strain-Ageing of Dead-Mild Steel Strip Used in the Pressing of Automobile Bodies and Accessories,” by Dr. J. W. Rodgers and Mr. H. A. Wainwright.

**Thursday, 4th April, 1940 : The Swansea Technical College Metallurgical Society.**

*Place and Time :* Royal Metal Exchange, Swansea, at 6 P.M.

*Chairman :* Mr. O. J. Thomas, President of the Swansea Technical College Metallurgical Society.

*Papers :*

"The Influence of Steel-Base Composition on the Rate of Formation of Hydrogen-Swells in Canned-Fruit Tinplate Containers. Part I," by Dr. T. P. Hoar, Mr. N. Morris and Mr. W. B. Adam.

"Practice in the Manufacture of Rimming Steel." Presented by Mr. James Mitchell. (This is a group of papers forming Section IV. of the Ninth Report on the Heterogeneity of Steel Ingots (*Special Report No. 27.*).

The Meetings were well attended and the interest shown in the papers was very gratifying. The Council wish to record their appreciation to the Presidents, Councils and Secretaries of the Local Societies, as well as to the authors of papers, for their contributions to the success of the Meetings.

The Manchester Metallurgical Society extended an invitation to Members of the Iron and Steel Institute resident in the Manchester district to attend a Lecture on "Use of the Microscope," given by Mr. H. Wrighton, which took place on Wednesday, March 6th, 1940, at 6.30 P.M., in the Engineers Club, Albert Square, Manchester. Mr. W. R. D. Manning, M.A., President of the Manchester Metallurgical Society, occupied the Chair.

#### RELATIONS WITH OTHER SOCIETIES AND TECHNICAL INSTITUTIONS.

The Council are glad to be able to report that the friendly relations with other Scientific Societies and Technical Institutions continue unabated.

*American Iron and Steel Institute.*—Mr. James Henderson (Hon. Treasurer) represented the Institute at the Forty-Eighth General Meeting of the American Iron and Steel Institute held in New York on 25th May, 1939, where he presented a paper on "The Manufacture, Sale and Use of Iron and Steel in Great Britain."

*Jernkontoret.*—The Secretary represented the Institute at a Meeting of Jernkontoret held in Stockholm on 3rd June, 1939.

*The Institute of Metals.*—The arrangements with the Institute of Metals whereby individuals can take up joint membership of the two Institutes at reduced fees, and the organisation by which close co-operation between the two bodies is assured are functioning satisfactorily. Six hundred and thirty-six Members and Associates of the Institute are now Members or Student Members of the Institute of Metals.

*Technical Societies outside Great Britain.*—Seven Members and Associates have taken advantage during the past year of the reciprocal arrangements between the Institute and the American Institute of Mining and Metallurgical Engineers, whereby they became Junior Foreign Affiliates of the American Institute on favourable terms. Similarly, four Members and Student Members of the A.I.M.E. have joined the Institute as Associates.

Under the agreement reached with Jernkontoret, Members may purchase *Jernkontorets Annaler* at specially reduced subscription rates, while members of the staffs of companies who are members of Jernkontoret may remain Associates up to the age of thirty.

Members of *l'Association des Ingénieurs Sortis de l'École de Liège* are also permitted to remain in the Associate Class until they are thirty years old.

*Participation in Meetings and Congresses.*—At the invitation of the Institute of British Foundrymen, the Institute took part in a Joint Meeting with that body, which was held at the Dorchester Hotel, Park Lane, London, on 16th June, 1939, at 2.30 P.M. During the International Foundry Congress the following papers were presented :

“Relationship between the Quality of Iron and Steel Castings and the Nature of the Materials of the Melt,” by Dr.-Ing. P. Bardenheuer.

“Organisation and Development of Steel Foundry Research,” by Wilfred John Dawson, Assoc. Met.

“Radiography in Iron and Steel Founding,” by F. W. Rowe, B.Sc.

“Notes on Dry-Sand Practice for Steel Castings,” by C. J. Dadswell, Ph.D., B.Sc., Ing.E.S.F., and T. R. Walker, M.A.

“The Renaissance of the Steel Casting and the Rôle of the Metallurgist,” by Frederick A. Melmoth.

Members of the Iron and Steel Institute were invited to attend a Meeting of the London Local Section of the Institute of Metals which was held at Caxton Hall, Westminster, on 8th February, 1940, at 7 P.M., when an address was given by Dr. S. W. Smith on “Some Considerations in the Training of Metallurgists.”

On 19th March, 1940, the Institution of Automobile Engineers organised a Symposium on Deep-Drawing Research in which the Iron and Steel Institute and the Institute of Metals were invited to co-operate. The Meeting took place in the James Watt Memorial Institute, York House, Great Charles Street, Birmingham, and commenced at 7 P.M. The following papers were presented :

“Drawing Tests for Sheet Metal,” by Professor H. W. Swift, M.A., D.Sc.

“The Quench-Ageing, Strain-Ageing and Cold-Working of Steel,” by Professor J. H. Andrew, D.Sc., J. W. Rodgers, Ph.D., H. A. Wainwright, M.Met., B.Eng., and J. N. Blackhurst.

“A Study of the Deep-Drawing Characteristics and Testing of Sheet Metals,” by Principal C. A. Edwards, D.Sc., F.R.S., R. Higgins, Ph.D., and T. D. Rees, B.Sc.

*Joint Committee on Materials and Their Testing.*—Beside the Institute, twenty-five Societies in Great Britain are represented on



this Committee, the Chairman of which was Sir Harold Carpenter, F.R.S., for the year beginning 1st April, 1939.

The purpose of this body is to act as the British national organisation in matters relating to materials and their testing, and it aims to promote joint discussions on the wider aspects of those subjects falling within the terms of reference, to assist a co-operating Institution or Society in the presentation of a paper or group of papers dealing with a more detailed aspect of one of the subjects falling within the terms of reference, and to undertake those duties with respect to international matters which properly devolve on the Joint Committee in accordance with its terms of reference.

*Engineering Public Relations Committee.*—The Institute has continued its membership of the Engineering Public Relations Committee formed by the Institution of Civil Engineers and consisting of representatives of fourteen Societies and Institutions.

*Co-operation with Local Technical Societies.*—The Council are pleased to report that friendly co-operation with a number of local Technical Societies has been continued. The arrangements which have been in force for some years, by which mutual collaboration is assured, provide for the holding of joint meetings, the supply of papers presented to the Iron and Steel Institute for reading at meetings of the Local Societies when they so desire, and for the extension of the maximum age of associate membership of the Institute from twenty-four to thirty in the case of those who are members of a Local Society.

The following is a list of the Societies with which arrangements on these lines have been concluded :

Cleveland Institution of Engineers.  
Ebbw Vale Metallurgical Society.  
Lincolnshire Iron and Steel Institute.  
Manchester Metallurgical Society.  
Newport and District Metallurgical Society.  
Sheffield Metallurgical Association.  
Sheffield Society of Engineers and Metallurgists.  
Staffordshire Iron and Steel Institute.  
Swansea Technical College Metallurgical Society.  
West of Scotland Iron and Steel Institute.

The Council value the co-operation which has been established, and wish to express their appreciation to the Councils and Members of the Societies concerned; they believe that active co-operation of this kind is in the best interests both of the Societies themselves and of the Institute.

A list of Meetings held during the autumn and winter months has been given above.



## PUBLICATIONS.

As announced in circulars issued during the year, it had been intended to issue the *Journal* monthly from January, 1940, and to use a larger size of page. Owing to the outbreak of war these changes have been deferred. Papers are, however, being issued monthly, beginning from January, 1940, in advance copy form.

The publication of the *Carnegie Scholarship Memoirs* has been discontinued, no volume having been published during the year, and from January, 1940, the publication of reports of the Research Committees in the Special Report Series has also been discontinued; Carnegie Scholarship papers and papers contributed by the Research Committees will be published in the *Journal*; in the event of Special Reports being published, appropriate announcements will be made.

Two volumes of the *Journal*, four Special Reports—the latter consisting of the “Second Report of the Alloy Steels Research Committee,” “Eighth Report on the Heterogeneity of Steel Ingots,” “First Report on Refractory Materials,” “Ninth Report on the Heterogeneity of Steel Ingots”—and three Supplementary Reports—Discussion, Correspondence and Replies on the “Second Report of the Steel Castings Research Committee,” “Eighth Report on the Heterogeneity of Steel Ingots” and the “First Report on Refractory Materials”—were published during the year.

The monthly *Bulletin of the Iron and Steel Institute* has also been published during the year, and is available to all Members on application without charge.

A List of Members was issued.

*Papers and Special Reports.*

The following four Special Reports, three Supplementary Reports and twenty-three papers were published during the year :

*Special Report No. 24.*—“Second Report of the Alloy Steels Research Committee.”

*Special Report No. 24A.*—“Discussion, Correspondence and Committee’s Reply on ‘Second Report of the Alloy Steels Research Committee’.”

*Special Report No. 25.*—“Eighth Report on the Heterogeneity of Steel Ingots.”

*Special Report No. 25A.*—“Discussion, Correspondence and Committee’s Reply on ‘Eighth Report on the Heterogeneity of Steel Ingots’.”

*Special Report No. 26.*—“First Report on Refractory Materials.”

*Special Report No. 26A.*—“Discussion, Correspondence and Reply on ‘First Report on Refractory Materials’.”

*Special Report No. 27.*—“Ninth Report on the Heterogeneity of Steel Ingots.”

F. G. BARKER : “Some Applications of the Spectrograph to the Quantitative Analysis of Ferrous and Non-Ferrous Metals.”

W. BETTERIDGE : “Nickel-Iron-Aluminium Permanent-Magnet Alloys.”

H. E. BLAYDEN, W. NOBLE and H. L. RILEY : “The Influence of Carbonising Conditions on Coke Properties. Part II.—The Effect of Pressure, Temperature, Rate of Heating and ‘Soaking’ on Coke Strength.”

- A. J. BRADLEY, F.R.S., and H. J. GOLDSCHMIDT : "An X-Ray Investigation of the Iron-Rich Nickel-Iron Alloys."
- E. W. COLBECK and R. P. GARNER : "The Effect of Nitrogen Additions and Heat Treatment on the Properties of High-Chromium Steels."
- C. A. EDWARDS, F.R.S., H. N. JONES and B. WALTERS : "A Study of 'Strain-Age-Hardening' of Mild Steel."
- H. ESCHER : "Ten Years' Development in Steam Engineering at the Port Kembla Steelworks, N.S.W., Australia" (Ablett Prize Paper).
- R. GENDERS and R. HARRISON : "Niobium-Iron Alloys."
- ROOSEVELT GRIFFITHS : "The Causes of 'Roll-Marks' on Tinplate."
- T. P. HOAR, T. N. MORRIS and W. B. ADAM : "The Influence of the Steel-Base Composition on the Rate of Formation of Hydrogen-Swells in Canned-Fruit Tinplate Containers.—Part I."
- H. JOLIVET : "Transformation of Austenite on Cooling; Morphology and Genesis of the Aggregates Formed."
- B. JONES and J. D. D. MORGAN : "Antimony in Mild Steel."
- COUNT BO KALLING and IVAR RENNERFELT : "Decarburisation of Granulated Pig Iron: The 'R.K.' Process."
- W. B. LAWRIE : "The Refining of Metal in the Basic Open-Hearth Furnace. The Influence of Fluorspar on the Process."
- A. L. NORBURY : "The Effect of Casting Temperature on the Primary Microstructure of Cast Irons. Theories of Dendrite Formation and of the Solidification of Iron-Carbon Alloys."
- L. NORTHCOTT : "The Application of the Durville Rotatory Process to the Casting of Steel."
- W. J. REES : "Note on the Slow Cooling of Ingots."
- J. W. RODGERS and H. A. WAINWRIGHT : "The Strain-Ageing of Dead-Mild Steel Strip Used in the Pressing of Automobile Bodies and Accessories."
- T. F. RUSSELL : "Interpretation of Thermal Curves and some Applications to Ferrous Alloys."
- HAAKON STYRI : "Slag Inclusions and Acid Open-Hearth Refining of High-Carbon Steel."
- H. W. SWIFT : "Tensional Effects of Torsional Overstrain in Mild Steel."
- C. SYKES and F. W. JONES : "Note on Discontinuities in the Resistance-Temperature Curves of Commercially Pure Iron and Steel."
- T. WILSON : "The Rolling of Sections at the Appleby-Frodingham Steel Co., Ltd."

## JOINT LIBRARY AND INFORMATION DEPARTMENT.

### *Joint Library.*

The routine work of the Joint Library has been carried out normally throughout the year. Requests for the loan of volumes and technical information tended to increase; over 4,000 volumes were sent out on loan, to Members, industrial companies and research establishments.

On the outbreak of war a licence was received to obtain German technical publications, and these are available to Members as usual.

Many important text-books have been added, and the Council wish to take this opportunity of thanking those authors and publishers who have made presentations to the Library. A list of the additions made to the Library is issued quarterly, and copies will be sent to Members on request.

The Joint Library Advisory Committee, under the Chairmanship of Dr. C. H. Desch, F.R.S., held two meetings during the year.

*Collaboration with the Institution of Civil Engineers and the Science Library.*

The valuable collections of scientific works included in the Science Library and the Library of the Institution of Civil Engineers are available for consultation or loan under certain conditions. Members who wish to avail themselves of these facilities should communicate with the Librarian of the Joint Library, 4 Grosvenor Gardens, London, S.W.1.

*The Bulletin of the Iron and Steel Institute.*

Members have been kept informed of developments in iron and steel manufacture and ferrous metallurgy by means of the *Bulletin of the Iron and Steel Institute*, which contains abstracts of the important technical literature published in Great Britain and other countries. The *Bulletin* is published monthly, and is supplied free of charge to members on application. The subscription rate to non-members is 30s. per annum (\$6 to members of the American Iron and Steel Institute, the American Institute of Mining and Metallurgical Engineers and the American Society for Metals).

The majority of the articles abstracted in the *Bulletin* are filed in the Library, and are available for loan. The original articles can be purchased for Members on request, and photographic copies can be supplied under certain conditions.

*Information Department.*

Much progress has been made with the work of the Information Department, and the number of enquiries has increased. Although the publication of bibliographies has been temporarily suspended, many bibliographies have been compiled, especially at the request of Members. Members are invited to avail themselves of the bibliographical and information services.

The following translations were prepared and copies are available for consultation in the Library or for purchase, at a nominal charge :

- No. 14.—“Impermeability of Metals and Alloys under High Pressure as a Function of Casting Conditions,” by G. Welter and J. Mikolajczyk. (Translated from the Polish.)
- No. 15.—“The Theory of the Removal of Hydrogen in the Electric Furnace Melting of Steel,” by N. M. Chuyko. (Translated from the Russian.)
- No. 16.—“Factors Influencing the Surface of Alloy-Steel Ingots and the Rôle of the Ingot Mould Wash,” by A. Pelevin. (Translated from the Russian.)

- No. 17.—“ Production and Properties of Fe-Cr-Al Heat-Resisting Alloys with High Electrical Resistance,” by M. Pridantsev and N. Semenova. (Translated from the Russian.)
- No. 18.—“ The Hardening of Steel with Particular Reference to the Influence of the Quenching Medium on the Hardening Process,” by Adolf Rose. (Translated from the German.)

## RESEARCH.

*Iron and Steel Industrial Research Council.*

Collaboration with the Iron and Steel Industrial Research Council has been maintained, and the Institute has continued to take an important part in the joint research activities of the industry. The Council wish to express their appreciation of the assistance given by the Department of Scientific and Industrial Research to scientific and technical development in the industry, and to the British Iron and Steel Federation and the Iron and Steel Industrial Research Council for their valuable co-operation. They wish also to thank the Associations, Companies and individuals who have contributed generously in time and money to research, and to express their appreciation of the valuable work which is being done by many Government, University, industrial and private laboratories.

*Technical Advisor to the Iron and Steel Industrial Research Council.*

Dr. C. H. Desch, F.R.S., on relinquishing the position of Superintendent of the Metallurgy Department of the National Physical Laboratory at the end of 1939, took up the appointment of Technical Advisor to the Iron and Steel Industrial Research Council. He has his headquarters at the Offices of the Iron and Steel Institute, which is now able to take advantage of his valuable experience and advice.

*Technical Committees.*

The following four Committees are Joint Committees of the Institute and the Iron and Steel Industrial Research Council engaged on co-operative research; the list includes the Sub-Committees appointed by the Committees.

**Alloy Steels Research Committee :** Chairman, Dr. W. H. Hatfield, F.R.S. Established June, 1934. Meetings held during 1939 : six.

*Sub-Committee A, Thermal Treatment :* Chairman, Mr. P. B. Henshaw. Established January, 1936. Meetings held during 1939 : five.

*Hair-Line Crack Sub-Committee :* Chairman, Dr. W. H. Hatfield, F.R.S. Established July, 1938. Meetings held during 1939 : five.



**Corrosion Committee :** Chairman, Dr. W. H. Hatfield, F.R.S. Established July, 1928. Meetings held during 1939 : six.

*Laboratory Research Sub-Committee :* Chairman, Dr. U. R. Evans. Established June, 1930. No meetings held during 1939 ; activities carried on mainly by correspondence between Members.

*Protective Coatings Sub-Committee :* Chairman, Mr. T. M. Herbert. Established January 1936. Meetings held during 1939 : two.

*Marine Corrosion Sub-Committee :* Chairman, Dr. G. D. Bengough, F.R.S. Re-formed November, 1938. Meetings held during 1939 : three.

**Heterogeneity of Steel Ingots Committee :** Chairman, Dr. W. H. Hatfield, F.R.S. Established May, 1924. Meetings held during 1939 : six.

*Liquid Steel Temperature Sub-Committee :* Chairman, Mr. E. W. Elcock. Established March, 1929. Meetings held during 1939 : one.

*Ingot Moulds Sub-Committee* (joint with the Open-Hearth Committee of the Iron and Steel Industrial Research Council) : Chairman, Mr. R. H. Myers. Established November, 1934. Meetings held during 1939 : three.

*Oxygen Sub-Committee :* Chairman, Dr. T. Swinden. Established January, 1936. Meetings held during 1939 : one (Chemists' Panel, one).

*Inclusions Sub-Committee :* Chairman, Dr. W. H. Hatfield, F.R.S. Established November, 1936. Meetings held during 1939 : four.

*Joint Conference on the Physical Chemistry of Steelmaking* (formed jointly by the Committee on the Heterogeneity of Steel Ingots and the Open-Hearth Committee of the Iron and Steel Industrial Research Council) : Chairman, Dr. T. Swinden. Established September, 1938. No meetings held during 1939.

*Standard Methods of Analysis Sub-Committee :* Chairman, Dr. E. Gregory. Established, September, 1939. Meetings held during 1939 : two.

**Steel Castings Research Committee :** Chairman, Mr. W. J. Dawson. Established November, 1934. Meetings held during 1939 : four.

*Moulding Materials Sub-Committee :* Chairman, Mr. W. J. Rees. Established March, 1936. Meetings held during 1939 : four.

*Foundry Practice Sub-Committee :* Chairman, Mr. F. H. Lloyd. Established May, 1938. Meetings held during 1939 : three.

The Second Report of the Alloy Steels Research Committee and the Eighth and Ninth Reports on the Heterogeneity of Steel Ingots were published during the year.

#### APPOINTMENT OF REPRESENTATIVES.

The following is a list of the Institute's representatives on various governing bodies and committees for the year 1939 ; it has been brought up to date to March 31, 1940 :

BRITISH ASSOCIATION, Fuel Economy Committee : Sir Robert Hadfield, Bt., F.R.S.



BRITISH CAST IRON RESEARCH ASSOCIATION : Professor T. Turner.

BRITISH CORPORATION REGISTER OF SHIPPING AND AIRCRAFT,  
Committee of Management and Technical Committee :  
Dr. A. McCance.

BRITISH ELECTRICAL AND ALLIED INDUSTRIES RESEARCH  
ASSOCIATION,

Sub-Committee J/E, Joint Committee, Steels for High  
Temperatures : Dr. W. H. Hatfield, F.R.S., Dr. T.  
Swinden.

Sub-Committee J, Earthing to Water Mains : Dr. J. C.  
Hudson.

BRITISH IRON AND STEEL FEDERATION, Statistical Committee :  
Mr. K. Headlam-Morley.

BRITISH REFRACTORIES RESEARCH ASSOCIATION, Council : Mr.  
W. J. Brooke.

BRITISH STANDARDS INSTITUTION,

Chemical Engineering Divisional Council : Mr. E. F. Law.

Engineering Divisional Council E/- : The Hon. R. G.  
Lyttelton, Mr. James Henderson, Mr. J. Sinclair Kerr.

Sub-Committee M33/7, Protective Glasses for Welders and  
Industrial Purposes : Dr. C. H. Desch, F.R.S.

Technical Committee CEB/1, Cement : Mr. F. W. Harbord,  
C.B.E.

Technical Committee CEB/6/1, Concrete Blocks : Mr. F. W.  
Harbord, C.B.E.

Technical Committee CH/17, Symbols used in Diagrams of  
Chemical Engineering Plant : Mr. A. E. Chattin.

Technical Committee EL/28, Fans : Mr. A. F. Webber.

Iron and Steel Industry Committee IS/- : Dr. T. Swinden.

Technical Committee IS/1, Co-ordination of Iron and Steel  
Specifications : Dr. T. Swinden.

Technical Committee IS/6, Steel Castings : Dr. R. H. Greaves.

Technical Committee IS/8, Creep Properties : Dr. W. H.  
Hatfield, F.R.S.

Technical Committee IS/15, Iron and Steel for Shipbuilding :  
Sir Edward J. George.

Technical Committee IS/17, Cast Iron Columns for Street  
Lighting : Mr. J. G. Pearce.

Technical Committee IS/35, Cast Iron : Mr. H. B. Toy.

Technical Committee IS/35/3, Malleable Steel Castings :  
Mr. C. H. Kain.

Technical Committee ME/22, Marking and Colouring of  
Foundrymen's Patterns : Mr. F. W. Lewis.

Technical Committee ME/23, Brinell Hardness Testing :  
Dr. W. H. Hatfield, F.R.S.

Technical Committee ME/25, Testing of Thin Metal Sheet  
and Strip : Dr. T. Swinden.

Technical Committee ME/32, Engineering Symbols and Abbreviations : Dr. T. Swinden.

Solid Fuel Industry Committee, SF/- : Mr. A. F. Webber.

Technical Committee SF/1, Nomenclature and Definitions : Mr. A. F. Webber.

Technical Committee, SF/2 Underfed Screw Type Stokers : Mr. A. F. Webber.

Technical Committee SF/4, Heating Stoves : Mr. A. F. Webber.

Technical Committee on Metallic Finishes : Mr. F. C. Platt.

Units and Technical Data Co-ordinating Committee : Sir Wm. Larke, K.B.E.

CITY AND GUILDS OF LONDON INSTITUTE, Advisory Committee on Metallurgy : Mr. E. C. Greig.

CONSTANTINE COLLEGE, Advisory Committee : Mr. E. W. Jackson.

EMPIRE COUNCIL OF MINING AND METALLURGICAL INSTITUTIONS : Mr. F. W. Harbord, C.B.E., Mr. K. Headlam-Morley.

ENGINEERING PUBLIC RELATIONS COMMITTEE,

Main Committee : Mr. James Henderson.

Executive Committee : Mr. K. Headlam-Morley.

HONG-KONG UNIVERSITY, Home Committee : Sir Robert Hadfield, Bt., F.R.S.

IMPERIAL COLLEGE OF SCIENCE AND TECHNOLOGY, Board of Governors : Mr. James Henderson.

IMPERIAL INSTITUTE, Mineral Resources Department, Iron and Ferro-Alloy Metals Committee : Mr. K. Headlam-Morley.

INSTITUTE OF FUEL, Council : Mr. F. W. Harbord, C.B.E.

INSTITUTE OF WELDING, Council and Representative of Patron Institution : Mr. K. Headlam-Morley.

INSTITUTION OF MECHANICAL ENGINEERS, Research Committee on High-Duty Cast Irons for General Engineering Purposes : Mr. K. Headlam-Morley.

IRON AND STEEL INDUSTRIAL RESEARCH COUNCIL : Mr. F. W. Harbord, C.B.E., Dr. W. H. Hatfield, F.R.S., Mr. K. Headlam-Morley.

JOINT COMMITTEE ON MATERIALS AND THEIR TESTING : Mr. K. Headlam-Morley.

LIVERPOOL UNIVERSITY, Court of Governors : Sir W. Peter Rylands, Bt.

LLOYD'S REGISTER OF SHIPPING, Technical Committee : Mr. James Henderson, Mr. P. Baxter.

MECHANISATION BOARD (Army Council) : Mr. F. W. Harbord, C.B.E.

METALLIFEROUS MINING AND QUARRYING INDUSTRIES, Advisory Committee : *appointment open.*

NATIONAL PHYSICAL LABORATORY, General Board : Dr. A. McCance, Dr. T. Swinden.

RAMSEY MEMORIAL LABORATORY, Advisory Committee : Mr. F. W. Harbord, C.B.E.

ROYAL SCHOOL OF MINES, Advisory Board : Mr. F. W. Harbord, C.B.E.

ROYAL SOCIETY, General Board for Administering Government Grants for Scientific Investigations : The President.

SCHOOL OF METALLIFEROUS MINING (CORNWALL), Board of Governors : Mr. J. S. Hollings.

SCIENCE MUSEUM, Advisory Council : Sir Harold Carpenter, F.R.S.

SHEFFIELD UNIVERSITY, Court of Governors : Sir Robert Hadfield, Bt., F.R.S.

[The Statement of Accounts for 1939 will be found in the following pages.]

# THE IRON AND BALANCE SHEET,

LIABILITIES.									
							£	s.	d.
Sundry Creditors :—									
Office Rent	...	...	...	...	...	...	300	0	0
Postages	...	...	...	...	...	...	5	6	1
Telephone Calls	...	...	...	...	...	...	12	12	8
Telegrams	...	...	...	...	...	...	3	15	0
Printing and Stationery	...	...	...	...	...	...	42	10	2
Travelling Expenses	...	...	...	...	...	...	9	0	0
Library Books	...	...	...	...	...	...	23	1	3
Sundries	...	...	...	...	...	...	10	17	6
Cleaning, Heating, Lighting and Water	...	...	...	...	...	...	132	2	7
Journal Publishing, etc.	...	...	...	...	...	...	39	0	9
Bulletin	...	...	...	...	...	...	89	9	4
Translation Service	...	...	...	...	...	...	13	2	0
Yearly Index	...	...	...	...	...	...	24	13	0
Autumn Meeting	...	...	...	...	...	...	27	11	0
Grants	...	...	...	...	...	...	6	0	0
International Association for Testing Materials	...	...	...	...	...	...	17	3	7
Corrosion Committee	...	...	...	...	...	...	41	6	4
Alloy Steels Research Committee	...	...	...	...	...	...	105	3	11
Heterogeneity of Steel Ingots Committee	...	...	...	...	...	...	10	18	2
Steel Castings Research Committee	...	...	...	...	...	...	7	15	0
Institute of Metals	...	...	...	...	...	...	3	13	6
No. 4, Grosvenor Gardens	...	...	...	...	...	...	13	15	9
									938 17 7
Subscriptions in Advance :—									
Home Members	...	...	...	...	...	...	30	0	0
Overseas Members	...	...	...	...	...	...	41	1	0
Associate Members	...	...	...	...	...	...	7	2	0
									78 3 0
Entrance Fees in Advance	...	...	...	...	...	...			3 3 0
Journal Sales :—									
Amount in Advance, 1940	...	...	...	...	...	...	36	8	9
Received on Account of Volume No. II., 1939	...	...	...	...	...	...	397	0	5
									433 9 2
Suspense Account as at 1st January, 1939 :—									
Reserve for 10-year Index	...	...	...	...	...	...	200	0	0
Add Further Transfer, 1939	...	...	...	...	...	...	50	0	0
									250 0 0
Entrance Fees	...	...	...	...	...	...	1,634	10	0
Add Further Transfer, 1939	...	...	...	...	...	...	277	4	0
									1,911 14 0
									2,161 14 0
Life Composition Fund	...	...	...	...	...	...			3,259 14 8
Iron and Steel Institute :—									
Capital as per last Balance Sheet	...	...	...	...	...	...	23,873	12	4
Add Profit on Sale of £1,000 Port of Calcutta	...	...	...	...	...	...			
4% Bonds	...	...	...	...	...	...	17	10	0
Deduct Loss on Sale of £800 Port of Bombay	...	...	...	...	...	...			
4% Bonds	...	...	...	...	...	...	9	0	0
									8 10 0
									23,882 2 4
Reserve Account—									
Accumulated Excess of Income over Expenditure	...	...	...	...	...	...	2,945	17	2
Less Symposium on Steel-making, 1938	...	...	...	...	...	...	863	1	10
Excess of Expenditure over Income now written off	...	...	...	...	...	...	2,082	15	4
Deduct Excess of Expenditure over Income for the year	...	...	...	...	...	...	227	10	3
									1,855 5 1
									25,737 7 5
								<u>£32,612 8 10</u>	

I have examined the above Balance Sheet

# STEEL INSTITUTE.

31st DECEMBER, 1939.

ASSETS.						£	s.	d.	£	s.	d.
Sundry Debtors :—											
Subscriptions in Arrear ... ..	...	...	...	...	...				Not Valued.		
Amount due from Carnegie Scholarship Fund ... ..	...	...	...	...	...	229	3	4			
Telephone Deposit ... ..	...	...	...	...	...	1	0	0			
Travelling Expenses ... ..	...	...	...	...	...	8	0	0			
Telephone ... ..	...	...	...	...	...	28	4	11			
Air-Raid Precautions ... ..	...	...	...	...	...	13	15	0			
Salaries ... ..	...	...	...	...	...	10	0	0			
Sundries ... ..	...	...	...	...	...	4	13	3			
Income Tax Recoverable ... ..	...	...	...	...	...	937	7	1			
Rents Receivable ... ..	...	...	...	...	...	275	0	0			
Publishing Expenses :—											
Printing ... ..	...	...	...	...	...	36	8	0			
Abstracts ... ..	...	...	...	...	...	34	10	6			
Reviews ... ..	...	...	...	...	...	13	17	0			
Translations ... ..	...	...	...	...	...	15	10	0			
Advance Copies ... ..	...	...	...	...	...	86	3	0			
									186	8	6
Blast-Furnace Symposium ... ..	...	...	...	...	...	14	2	6			
Corrosion Committee ... ..	...	...	...	...	...	5	15	2			
									1,713		9
Payments in Advance :—											
Journal Sales ... ..	...	...	...	...	...	409	12	0			
Insurance ... ..	...	...	...	...	...	32	5	10			
Library Books ... ..	...	...	...	...	...	19	5	3			
Staff Superannuation Fund ... ..	...	...	...	...	...	173	3	8			
Rates ... ..	...	...	...	...	...	10	5	10			
Grants ... ..	...	...	...	...	...	50	0	0			
									694	12	7
Stock of Journals ... ..	...	...	...	...	...				Not Valued.		
Office Furniture and Library ... ..	...	...	...	...	...				Not Valued.		
Cash at Bank and in Hand :—											
Secretary's Account ... ..	...	...	...	...	...	290	9	2			
Deposit Account ... ..	...	...	...	...	...	50	6	6			
Deposit Post Office Account ... ..	...	...	...	...	...	110	11	7			
Deposit Banque de Plovdiv, Bulgaria ... ..	...	...	...	...	...	5	5	0			
Cash at Office ... ..	...	...	...	...	...	122	12	4			
						579	4	7			
Less Overdraft on General Account ... ..	...	...	...	...	...	61	18	4			
									517	6	3
Investments at Cost per Schedule :—											
General Fund ... ..	...	...	...	...	...				24,904	15	4
(The Market Value of these Investments at 31st December, 1939, was £25,710 2s. 8d.)											
Symposium on Steel-making, 1938 :—											
As at 31st December, 1938... ..	...	...	...	...	...	1,115	18	8			
Expenditure incurred to date ... ..	...	...	...	...	...	1	1	0			
						1,116	19	8			
Less Sales to 31st December, 1939 ... ..	...	...	...	...	...	253	17	10			
Balance written off per contra ... ..	...	...	...	...	...	863	1	10			
Research Committee Account :—											
Amount advanced ... ..	...	...	...	...	...				385	0	3
Life Composition Fund :—											
Investments at Cost per Schedule ... ..	...	...	...	...	...				3,259	14	8
(The Market Value of these Investments at 31st December, 1939, was £2,943 6s. 2d.)											
4. Grosvenor Gardens :—											
Structural Alterations and Decorations, Furnishing, Legal Charges and Incidental Expenses—											
As at 1st January, 1939 ... ..	...	...	...	...	...	13,683	18	6			
Further expenditure during year ... ..	...	...	...	...	...	160	4	1			
do. A.R.P. ... ..	...	...	...	...	...	326	15	5			
									486	19	6
									14,170	18	0
Less Subscriptions received ... ..	...	...	...	...	...	13,033	8	0			
									1,137	10	0
									£32,612	8	10

of the Institute and certify it to be correct.

(Signed) W. B. KEEN,  
Chartered Accountant.



## INCOME AND EXPENDITURE ACCOUNT

1938.		INCOME.												
£	£		£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.
		Entrance Fees ... ..	138	12	0									
		Do. Companies' Nominations ... ..	138	12	0									
423	—	Less Transferred to Reserve Fund ...				277	4	0						
						277	4	0						
		Annual Subscriptions :—												
4,335		Members, Home—Current ... ..	4,382	19	3									
148		Do. Companies' Nominations ... ..	134	8	0									
122		Do. Arrears ... ..	173	5	0									
	4,605								4,690	12	3			
1,745		Members, Overseas—Current ... ..	1,802	11	1									
66		Do. Companies' Nominations ... ..	4	4	0									
106		Do. Arrears ... ..	123	19	10									
	1,917								1,930	14	11			
179		Associates—Current ... ..	186	18	0									
8		Do. Companies' Nominations ... ..	11	11	0									
—		Do. Arrears ... ..	8	18	6									
	187								207	7	6			
		Sales of Publications :—												
1,493		Journals ... ..	1,651	9	9									
39		Bulletin ... ..	111	6	0									
	1,532								1,762	15	9			
		Interest on Investments (Gross) :—												
1,059		General Fund ... ..	1,058	12	8									
120		Life Composition Fund ... ..	138	19	3									
16		Bessemer Medal Fund ... ..	16	0	0									
	1,195								1,213	11	11			
61		Income Tax Recovered to 31st December, 1937												
17		Interest on Deposit Accounts ... ..							6	1	0			
6		Sundry Receipts ... ..							13	2	9			
		Institute of Metals :—												
		Rent Receivable ... ..	750	0	0									
		Contribution to Joint Library ... ..	350	0	0									
	550								1,100	0	0			
		Iron and Steel Industrial Research Council :—												
		Grant for Bulletin ... ..	750	0	0									
		Grant for Secretarial Services ... ..	2,000	0	0									
		Grant for Information Service ... ..	500	0	0									
	3,250								3,250	0	0			
		Carnegie Research Fund :—												
150		Transfer in respect of Grant ... ..							50	0	0			
10		Welding Symposium ... ..												
		Balance, being Excess of Expenditure over												
2,327		Income carried down ... ..							4,054	18	7			
<u>£15,807</u>			<u>£18,279</u>		4	8								
	£					£	s.	d.	£	s.	d.			
		Special Contributions :—												
2,853		Contributions receivable during 1939 ...	3,292	4	0									
		Income Tax Recoverable ... ..	873	19	4				4,166	3	4			
		Balance, being Excess of Expenditure over												
		Income for the year ... ..							227	10	3			
<u>£2,853</u>			<u>£4,393</u>		18	7								

FOR THE YEAR ENDED 31ST DECEMBER, 1939.

## EXPENDITURE.

1938.	£	£		£	s.	d.	£	s.	d.
			Salaries (including Pensions and Overtime)...	6,747	8	3			
			Less Contribution from Carnegie Research Fund ... ..	150	0	0			
6,054							6,597	8	3
47			National Insurance ... ..				48	9	0
285			Staff Superannuation Fund ... ..				340	14	5
924			Office Rent ... ..				1,200	0	0
			Repairs and Decorations ... ..				24	5	9
450			Cleaning, Heating, Lighting and Water ... ..				770	17	4
196			Library Books, Binding, etc. ... ..				368	17	10
92			Office Furniture ... ..				245	3	9
149			Annual Meeting ... ..				142	11	2
131			Autumn Meeting ... ..				161	13	2
			Publishing Expenses:—						
1,563			Journal—Printing and Paper	2,254	1	3			
36			Translations and Reviews ... ..		22	10	6		
165			Postage ... ..		211	10	11		
							2,488	2	8
191			Advance Copies—Printing ... ..		314	18	1		
75			Postage ... ..		129	12	7		
							444	10	8
726			Bulletin—Printing ... ..		575	0	2		
102			Postage ... ..		76	18	4		
							651	18	6
139			Bibliographies ... ..						
152			List of Members ... ..				141	19	9
3,149							3,726	11	7
576			Stationery and Printing ... ..				707	0	10
247			Postage and Receipt Stamps ... ..				400	1	0
196			Travelling and Entertainment Expenses ... ..				241	13	2
10			Insurance ... ..				64	2	3
32			Auditors' Fees for Year, 1938 ... ..				31	10	0
109			Telephone Rental and Calls ... ..				135	11	6
215			Office Disbursements and Sundry Expenses... ..				228	13	0
15			Translation Service ... ..				45	3	0
95			Bank Interest and Charges ... ..				77	3	2
92			Removal Expenses ... ..						
27			Bessemer Medal ... ..				21	12	6
			Grants:—						
			Joint Committee on Materials and their Testing ... ..		10	10	0		
			British Refractories Research Association		25	0	0		
			Institution of Mechanical Engineers, Research on High Duty Cast Iron ... ..		25	0	0		
			British Electrical and Allied Industries Research Association ... ..		50	0	0		
			British Standards Institution ... ..		50	0	0		
			Engineering Public Relations Fund ... ..		2	2	0		
			British Foundry School ... ..		10	10	0		
			Sheffield University Foundry Courses ... ..		21	0	0		
			British Standards Institution, International Meeting, Helsinki ... ..		6	0	0		
216							200	2	0
2,500			Iron and Steel Industrial Research Council Grant ... ..				2,500	0	0
£15,807							£18,279	4	8
£				£	s.	d.	£	s.	d.
2,327			Balance brought down ... ..				4,054	18	7
50			Transfer Reserve Account 10-year Index ... ..				50	0	0
			Do. Companies' Nominations:—						
151			Entrance Fees ... ..				138	12	0
			Subscriptions Account:—						
148			Home Members ... ..		134	8	0		
66			Overseas Members ... ..		4	4	0		
7			Associates ... ..		11	11	0		
							150	3	0
							288	15	0
104			Excess of Income over Expenditure for the year ... ..						
£2,853							£4,393	13	7

## WILLIAMS PRIZE FUND.

## BALANCE SHEET, 31st DECEMBER, 1939.

LIABILITIES.		ASSETS.	
£	s. d.	£	s. d.
Capital Account representing the Market Value of £3,000 3¼% Conversion Loan at 21st September, 1926, when Fund was inaugurated ... ..		£3,452 15s. 7d. 3¼% Conversion Loan (at cost) ... ..	
Income and Expenditure Account :—		Cash at Bank ... ..	
Balance as at 1st January, 1939 ... ..		(The Market Value of this Security at 31st December, 1939, was £3,245 12s. 3d.)	
Add Excess of Income over Expenditure for the year to 31st December, 1939 ...		2,670 0 0	
20 16 2		80 6 8	
530 6 8		2,750 6 8	
		£2,750 6 8	

## INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31st DECEMBER, 1939.

INCOME.		EXPENDITURE.	
£	s. d.	£	s. d.
Interest on 3¼% Conversion Loan ... ..		Award ... ..	
120 16 10		Sundry Expenses ... ..	
...		Excess of Income over Expenditure for the year ... ..	
120 16 10		100 0 0	
		20 16 2	
		£120 16 10	

## BALANCE SHEET. 31ST DECEMBER, 1939.

1940—i

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31ST DECEMBER, 1939.

E

## THE IRON AND STEEL INSTITUTE.

## SCHEDULE OF INVESTMENTS AT 31st DECEMBER, 1939.

## SHOWING NOMINAL VALUES, COST VALUES AND PRESENT MARKET VALUES.

Nominal Value.	£ s. d.	Market Value, 31st December, 1939.	Cost Value.	Nature of Security.	GENERAL FUND OF THE INSTITUTE.	LIFE COMPOSITION FUND.
2,197 7 0	£	2,054 4 10	£	...	...	...
1,324 7 4	s.	1,244 17 10	s.	...	...	...
447 0 0	d.	436 16 6	d.	...	...	...
1,872 0 0	...	1,188 14 4	...	...	...	...
2,241 0 0	...	1,624 14 6	...	...	...	...
2,649 4 0	...	1,814 6 0	...	...	...	...
1,500 0 0	...	877 10 0	...	...	...	...
2,954 1 0	...	3,095 16 10	...	...	...	...
437 0 0	...	273 2 6	...	...	...	...
12,242 19 3	...	13,099 19 4	...	...	...	...
		<u>£25,710 2 8</u>				
		<u>£24,904 15 4</u>				
587 13 10	...	528 18 5	...	...	...	...
50 10 0	...	40 13 0	...	...	...	...
1,330 0 0	...	831 5 0	...	...	...	...
594 0 0	...	620 14 7	...	...	...	...
205 15 6	...	192 7 11	...	...	...	...
681 13 0	...	729 7 3	...	...	...	...
		<u>£2,943 6 2</u>				
		<u>£3,259 14 8</u>				



Nominal Value.	£	s.	d.	Nature of Security.			Market Value, 31st December, 1939.			Cost Value.
				ANDREW CARNEGIE RESEARCH FUND.						
3½% War Stock	6,897	14	11	...	...	...	...	...	£	s. d.
3½% Conversion Loan	2,693	12	0	...	...	...	...	...	6,895	16 6
3% Local Loans	227	9	4	...	...	...	...	...	2,006	19 0
India 3½% Stock, 1931	2,300	0	0	...	...	...	...	...	2,531	19 8
India 3% Stock, 1948	2,560	4	0	...	...	...	...	...	183	2 2
North Eastern Electric Supply Company 3½% Consolidated Debenture Stock	2,250	0	0	...	...	...	...	...	1,897	10 9
Great Western Railway 4% Debenture Stock	1,500	0	0	...	...	...	...	...	1,804	18 9
London Midland and Scottish Railway 4% Debenture Stock	2,000	0	0	...	...	...	...	...	2,081	5 0
London and North Eastern Railway 4% 1st Guaranteed Stock	1,312	0	0	...	...	...	...	...	1,482	0 0
Do. do. 4% Debenture Stock	5,000	0	0	...	...	...	...	...	1,790	0 0
Do. do. 3% Debenture Stock	6,000	0	0	...	...	...	...	...	951	4 0
				...	...	...	...	...	4,125	0 0
				...	...	...	...	...	3,750	0 0
				...	...	...	...	...	£27,046	7 5
				...	...	...	...	...	£25,355	16 10

3,452	15	7	3½% Conversion Loan ...	...	...	...	...	...	...	£3,245	12	3
										£2,670	0	0

Trustees :—Sir Harold Carpenter, Lord Airedale and Sir Francis Samuelson.

(Signed) JAMES HENDERSON,  
Hon. Treasurer.

(Signed) K. HEADLAM-MORLEY,  
Secretary.

I have examined the foregoing Balance Sheets and Income and Expenditure Accounts with the Books and Vouchers of the Institute and certify them to be correct. I have also verified the Balances at the Bankers and the Securities for the Investments shown above.

23 QUEEN VICTORIA STREET,  
LONDON, E.C. 4.  
13th March, 1940.

(Signed) W. B. KEEN,  
Chartered Accountant.



## PRESIDENTIAL ADDRESS.

BY JOHN CRAIG, C.B.E., D.L.

I DO acknowledge with appreciation the great honour which has been conferred upon me in being elected President of the Iron and Steel Institute. I recognise it is an honour balanced by responsibility. I cannot, however, hope to fill the office with the distinction displayed by many of my predecessors. They were able by their great technical knowledge and genius to contribute valuable additions to the science of steelmaking and to indicate how it could be successfully applied to the art. I am compelled, through my limitations, to follow in a simpler way some Past-Presidents who, like myself, have dealt more with the commercial than with the technical side of the industry. At the same time, I promise you that what I can do will be gladly done to support the Institute in its great work of seeking to unravel some of the mysteries that still exist in making steel.

I have been rather surprised to find that this high office has rarely been occupied by a representative from Scotland. Indeed, so far as I can trace, the only other President actively engaged in the industry in Scotland was the late Lord Invernairn.

I am conscious that the Institute is primarily for those engaged in the actual production of steel, and I appreciate that they would be more interested in my Address if I had some secrets to reveal to them, or suggestions to make which would enable them more efficiently to discharge their daily tasks. But there is no such fortune awaiting them. I fear I am not able to do more than recall some of the great changes which have taken place during my connection with the industry, but, in so doing, I would hope that the recollection of events which have impressed themselves on my memory as epoch-making will not merely be interesting, but will serve as an incentive to the younger Members of the Institute and create a determination that the next fifty years in the steel trade will be as remarkable as the past. Indeed, that is the only justification for recalling the past; there is never any justification for dwelling in the past.

In adopting such a course for my Address, I regret that it introduces to an undue degree the personal element. I have, however, this consolation, that Scotland illustrates in a concise manner the evolution of the industry—an evolution which, no doubt, is typical of what has happened throughout the world.

### AN HISTORICAL RETROSPECT.

It is significant that the industry, so far as iron is concerned, is a very ancient one, going back to the earliest pages of recorded

history, whereas steel, as we know it to-day, is a relatively modern product.

As you are aware, in Scotland blast-furnaces were first operated near the forests where charcoal was easily obtained, even although the iron ore and the workmen in many instances had to be brought from England. But when I first became conscious of the industry, it had moved down to the coalfields. Within a radius of twelve miles around the district in which I lived, there would be fifty to sixty blast-furnaces, all of which gave forth such a glare that the district was never in darkness—no doubt incidentally delaying the introduction of street lighting, as it was quite unnecessary. However, a depression set in and the lights began to go out. It was not a depression caused entirely by lack of trade. Other districts had adopted an improved blast-furnace, and it looked as if the day of the open-top Scottish blast-furnace was spent. However, something took place which gave it a new lease of life. The introduction of by-product recovery plant had found a value in the hitherto wasted gases. Many of the furnaces resumed operations, but this time without the glare. For another decade or two the blast-furnaces returned to comparative prosperity. However, the scene soon changed again, and it looked as if the introduction in other districts of larger furnaces, fired by coke, was to extinguish the blast-furnace in Scotland.

It was believed that Scottish coals, which had been so suitable in the open blast-furnace, had left no substitute that could be adapted to modern practice. But again developments took place which revealed that many of the Scottish coals were capable of making good metallurgical coke, and so to-day we have blast-furnaces linked not only to coke-ovens, but also to steelworks.

Certainly it is true that our industry can never become stationary. The lesson to be drawn from such vagaries is, I think, obvious. The extinction of an industry in a district generally arises from either lack of faith in the future or an unwillingness to utilise the increasing knowledge available from our scientists and inventors.

As to the future of the blast-furnace, who can say what it is to be? It may be that even in Scotland, where there is a superabundance of water power, we may yet see the electric blast-furnace.

#### STEEL'S BID FOR SUPREMACY.

Now, as regards steel, the changes have been even more impressive. When Sir William Siemens came to Scotland in the mid-'seventies, it was to demonstrate his new method of steelmaking, and by the early 'eighties steelworks were being laid down in Scotland. They were chiefly associated with malleable-iron works, so that it was a process of utilising the existing rolling mills so far as this was practicable.

It was just at this time—the early 'eighties—that there appeared what I have always looked upon as the dividing line between the free use of malleable iron and mild steel. The new Tay Bridge, built to replace the one blown down, was being made of malleable iron, and yet, before it was completed, the project of a larger bridge was in the hands of engineers, and when the Forth Bridge came to be designed in 1890, there was no thought that it should be of malleable iron. The engineers and those responsible for the splendid enterprise had been convinced that this bridge—great then and still great—must be made of what was then called the “new metal”—Siemens steel.

No doubt it was a grand adventure for the engineers to risk such an experiment. I think there is one thing that can be claimed for the pioneers of steelmaking, and that is “they builded better than they knew.” Some of their original ideas as regards the tensile and other characteristics of the steel which they proposed to use were so sound that even to-day there has been no need for any important changes. Indeed, speaking from a mere tensile point of view, the British Standard Specifications do not vary in any essential features from the specifications which were utilised in the building of the Forth Bridge. I say this because it bears eloquent testimony to the great vision of those who launched steel upon the world, and justified its very rapid acceptance as a base material upon which huge structures, in all branches of engineering, could be safely built.

About the same period the steel ship was rapidly coming into favour. The naval architect found—as the engineer had found—that he had wider scope for his ability with the new metal than he had ever enjoyed in the more restricted limits associated with malleable iron, and, indeed, one cannot imagine to-day what would have been the position if steel had not been at the disposal of naval architects. I cannot imagine that the 1,000-ft. ship would have been a possibility in any other metal.

#### CHANGING LABOUR CONDITIONS.

At this stage it may be interesting to digress and recall some of the conditions that did exist in those early days in a steelworks. Every department was flooded with men. The melting furnace was of 10 tons capacity and the ingots were taken to great hammers, around which one would find twelve to sixteen men handling the ingots with the aid of a peel. After being cut to size, the slabs were put on a bogie, which, pushed by six or eight men, placed them in the heating furnace by the help of a hand-winch. The majority of these heating furnaces were fired by coal.

In looking backwards, I think it may be assumed that one of the disadvantages which was associated with the earliest production of steel in Scotland was the low price of fuel. No doubt, at the



time, low prices were felt to be an advantage, but in the long view it did not prove to be so. I admit that when one could buy fuel at a few shillings per ton delivered into the works, there was not much incentive to spend capital to save fuel. Fortunately, other conditions of production led to the consideration of improved methods.

As one walked into a steelworks in the evening, with the smoky atmosphere arising from the coal-fired furnaces and the naphtha flares that were the only means of lighting, it was a weird sight. But changes were rapidly taking place. As the weight of the pieces being handled increased, the number of men had likewise to be increased, and the sheer impossibility of having more men around the furnaces, or at the rolls, forced the introduction of new appliances.

It was a great day when a cogging mill was first laid down and the hammers were demolished. The usual prophecies associated with developments were very frequent, and many of the older men expressed grave doubts as to the wisdom of using a cogging mill as compared with a hammer.

It is interesting to me to recall that many of the slabs which were being produced at this time were destined for America, where they were to be utilised for producing the first steel plates rolled in that great country.

With the cogging mill also came the live roller, and I feel sure it would be difficult for some of our younger Members to realise what an innovation it was to see this appliance first put to work. Perhaps, however, one of the more startling advances was the introduction of the charging machine to the melting furnace. This proved an event of first-rate importance and the charger was a show-piece for many a day.

Although by this time steelworks were scarcely ten years old, their geography had been very largely changed. The advent of electricity, of course, marked a great event and made possible many improvements. There had been a few overhead steam cranes, but the bulk of handling was done from the floor by steam cranes. Electricity, as first applied to lighting, was a great advance on the old practice.

By this time the cost of fuel, although very cheap as compared with to-day, had assumed an importance in the production of steel that called for serious consideration, and the waste-heat boiler applied to the melting furnace was heralded as a marked advance.

#### METALLURGICAL AND MECHANICAL DEVELOPMENTS.

There was a rapid advance, too, in the size and weight, if not in the quality, of the material being produced. This involved many engineering problems, both mechanical and electrical, and it must be admitted that the co-operation between the metallurgist and the engineer made rapid progress not only possible but reliable.

Employers were fortunate, however, in their men. Many of them had changed over from the production of malleable iron, and they applied such native ability and honesty of purpose that they played an important part in producing steel of the reliability to which I have referred. I believe that, notwithstanding what scientific knowledge we may acquire, we shall yet be indebted to the men at the bench and at the mill, and I hope it will ever be true that the steel industry can attract to itself men who find great pride in the material they produce. I have ever found it to be so in my very close contact with the craftsmen, and I am fully alive to the fact that there is being passed on to the next generation a heritage of which they should be proud and which, I hope, they will seek to enrich.

While it is true, as I have indicated, that in many aspects the pioneers laid down standards of quality which, until this day, have proved satisfactory for many purposes, yet it is to be admitted that the metallurgist has not been content to leave things as they were. I can remember with what suspicion and doubt the statement was received when it was indicated that the tensile strength of steel could be increased by heat treatment. Until that period, annealing was quite common, but it was principally associated with a reduction in tensile strength. There has been no more remarkable achievement in the field of metallurgy than that of heat treatment, and many of the greatest advantages to the engineering world have been derived from this source, and we are still only at the beginning of the full utilisation of this discovery.

To this advance came that of adding alloys to steel, and the possibilities in this direction would appear to be without limit. In more recent days, with the increased demands of the engineer, the development of steels to withstand heat has been the subject of much research, and now such steels can retain their virtues at comparatively high temperatures. What the next stage will be, I cannot foretell.

Great as were the inventions of Bessemer and, later, of Siemens, during the period under review, the advent of the electric melting furnace was an event of first-rate importance, and it will be difficult to foresee the possibilities that arise from this invention. The arc and the high-frequency furnace are just at the beginning of what must be a great career, and the very fact that the heat required may not necessarily come from coal must make this method of steel-making an interesting one and likely to lead to developments in districts hitherto considered unsuitable for steelmaking. In the past, iron- and steel-making have moved round, first from the forests to the coalfields and then to the ore-fields, and now they may go to the sources of water power.

#### A HALF-CENTURY OF PROGRESS.

Still, even recognising the advances which have taken place during this time, we are forced to think that this can only be the

beginning, for fifty years in the history of an industry is a short period. Who can say but that in the future the dream of eliminating the blast-furnace, while it may never come true in its entirety, may lead to some combination with the melting furnace that will substantially reduce the cost of transforming the iron ore into the steel ingot; and even the cogging mill may have to give place to some invention that will eliminate the ingot and transform the molten steel direct to an advanced form ready for the market.

We have witnessed the evolution from the coal-fired open-topped blast-furnace, with all its prodigal and wasteful use of fuel, to the modern blast-furnace, producing in a day twice as much iron as was produced in a week, and the development of the melting furnace producing instead of 100 tons per week probably twenty-five times that quantity. At the same time, raw fuel has been practically eliminated from the steelworks, for we now see coke-oven and blast-furnace gas being used to melt the steel and then to heat the ingot, the slab and the annealing furnace, and to raise steam to produce sufficient electricity for all the plant required to finish the steel ready for the market. I believe, too, that we are within sight of the abolition of raw coal even for the steam locomotive, as there appears to be no reason why it should not be fired with compressed coke-oven gas and thus bring us to the coal-less steelworks.

All this has happened in the past fifty years, and when someone fifty years hence addresses the Institute on somewhat similar lines to what I have done to-day, he will probably be able to record achievements which will be even greater than those to which I have referred.

#### COMMERCIAL ASPECT OF THE STEEL INDUSTRY.

I may be permitted to introduce to this Presidential Address a reference to the commercial aspect of the industry, seeing that it is with that that I have been more closely associated. I give place to no one in my admiration for the engineering and metallurgical progress that has been made and is still being made, but I am glad to say that there has been, particularly in recent years, a remarkable development of co-operation and goodwill on the commercial side. This applies not only to the makers in this country, but likewise to those in Europe and in America.

One of my earliest recollections of the industry was that, although a manufacturing business, it seemed to me to depend for its profits on successful speculation. It was a case of profits being made if there had been some successful buying or selling—if those in charge had been fortunate in catching the market for raw materials ahead of the time and selling before the market fell. This, I thought, was a misfortune for the industry, since it forced attention more upon the buying and selling than on the costs of production.

This is neither the place nor the occasion to introduce anything

controversial, but I am satisfied that the old policy which clamoured for competition and ever more competition would not stand the strain of modern social developments. These developments are symbolic of a change of attitude towards the great problems in commerce.

It has been an accepted theory for a very long time that trade thrives on competition. I know that the Manchester School believed—and possibly a remnant of the School still believes—that competition is synonymous with mere price-cutting. It is desirable, however, that the theory of competition should be considered on a broader basis.

### THEORY OF COMPETITION.

An industry can find within itself ample scope for competition in the improvement of quality, service and economic production, and this surely interprets competition on a greater and a finer basis. It is a policy which enables an industry to enjoy the fruits of its labour by providing funds for constantly and steadily taking advantage of every improvement in plant and methods made known through increasing knowledge. When competition merely affects price, the industry is not in a position to take advantage of such improvements, so that, in the long run, it is better, in my view, for the consumer to pay a reasonable price and rely upon the industry using a fair proportion of its profits to maintain its powers of production in an efficient condition.

These are advantages which cannot be associated with price-cutting, and so price control has had to take its place; and, with the experience gained over the last few years, I do not think that even consumers have any case against price control.

I have always held the view that the mere cutting of price cannot lead to a higher level of demand. In fact, in many cases the cutting of prices leads to a stagnation of demand by creating uncertainty. On the other hand, extravagant prices are equally bad, and the experience already gained in Great Britain of having price control based on costs goes to show that one of the beneficial effects is to keep prices from advancing to extreme limits. In other words, the tendency seems to be towards a stabilised price, and I am sure that, from all points of view, a controlled stable price is of greater service to the consumers of steel than the violent fluctuations of the past. I was interested to note that in an enquiry in America on this very aspect, the evidence submitted led to the conclusion that the cutting of prices had a very small effect, if any, upon increasing demand.

As far back as 1904, the British makers began to lay aside their stern individualism and discuss matters affecting the industry as a whole. Associations relating to one or two of the principal products had been formed and an attempt made to curb the intense



competition which was making the industry work either at no profit at all or at such a narrow margin of profit that it failed to provide funds for the constant improvement of the plant.

At the beginning of this century, the industry in this country was being affected more and more by the new works which were opening up in various parts of Europe and which, in their design, had benefited from all the skill of the pioneers in this country. This development intensified competition to a ruinous extent—competition made possible by a lavish expenditure of new capital and a strongly protected home market.

#### SALES AND CONTROL POLICIES.

However, even before 1914, some of the European makers had accepted an invitation to co-operate with the British makers in an attempt to introduce a more reasonable sales policy for rails, but the progress made was brought to an end in 1914. After the boom which followed for a brief period the cessation of hostilities in 1918, there came an acute period of depression, and the Continental makers flooded the world's markets with cheap steel. However, the larger minds of the industry, both in Europe and in Britain, realised that such a policy could only be short-lived. As a matter of fact, the Continental makers had already formed associations between the leading steel-producing countries in Europe and had made an attempt to regulate production and sales, but, so far, Britain had not taken any part in these arrangements and, unfortunately, Great Britain presented the largest and easiest market for Continental output. The effects were somewhat disastrous to Britain, and, although there were attempts to control it, no real progress was made. So long as Britain was prepared to allow its markets to be open without restriction, the temptation for the Continental makers was too great, and whatever may have been their theories or even their better judgment, no headway could be made towards a saner policy until the fiscal policy of this country was changed.

One of the great difficulties in dealing with the Continental makers was the fact that the British makers themselves were not properly organised. It is true that we had sales associations, but there was a lack of joint control, and it must be admitted that it was the advent of the reconstituted British Iron and Steel Federation, with a centralised policy and control of the industry as a whole, that made possible negotiations with the Continental makers and ultimately with the leading makers in America.

Thereafter, decided progress was made towards a policy of co-operation and joint control, and this happily was not confined to Europe but awakened American interest as well. No doubt such ideas were new to many of the producers and presented difficult problems not easy of solution. There was, however, a determination



among the makers in all the countries to find a solution of the many difficulties that were arising, and progress, if slow, was being made. I feel sure that, but for the unhappy events of the past year, this policy would have been consolidated.

Thus, I think that the leaders of the steel industry in all countries have shown wisdom in recognising the changed social conditions throughout the world and, instead of being dragged by them, have sought to regulate them not only for the benefit of the industry as a producer but even more so for the benefit of that great army of engineers who find steel essential for their varied schemes.

I think, therefore, that it will be admitted that the method recently adopted of regulating prices on a basis of cost is a sound one and should have the effect of forcing the industry at all times to consider its costs of production and then to regulate the selling price accordingly. To those who are fond of speculation, it may have robbed the industry of some of its charm, but I think it will make for a sounder basis in the future. It is a policy which will have its influence, I am sure, upon the efficiency of the industry, for it will help to prevent successful commercialism from hindering progress in the means of production.

#### STEEL'S FUTURE PROSPECTS.

While admitting that some of the pioneers in the industry showed great courage and possessed also sufficient optimism to carry them through many difficulties, they were not altogether free from pessimistic criticism. I remember Sir Hugh Bell telling me that his distinguished father, Sir Lowthian, had expressed the opinion that it was folly to seek to increase the output of pig iron in Britain when it had already reached 4,000,000 tons per year. Sir Lowthian held the view that there never could be a market for an increased output. I can well recall how, when one of my predecessors was anxious to build some additional open-hearth furnaces in the early 'nineties, a good friend of the Company appealed to his senior to stop what he described as the folly of the young man in desiring to make more steel, because the country could never consume it. It is always a difficult problem to know how to handle the periodic waves of pessimism which seem to creep over the world from time to time. Yet I think it can be safely assumed that the best time to build new furnaces is when the prophets declare that the country has too great a productive capacity. It would seem that those who have acted on this policy in the past have nothing to regret.

It would be difficult indeed to say when a country has sufficient steel for all its requirements. The general advance in civilisation seems to move with an increased output of steel. Whether it is steel that makes civilisation or civilisation that makes the demand for steel is a problem that I leave with you, but the fact remains

that the two have grown together, and it does appear as if each step forward in civilisation demands more steel, and that with the production of increased quantities and improved qualities of steel, an increase takes place in the standard of living, and so civilisation marches on. The luxuries of life are associated with steel, and while it may be that there are critics to-day who regret the development of the tin-opener and look upon it as a sign of decadence in domestic life, there can be no denying the fact that the tin can is providing the public with luxuries which, without it, would be quite impossible. It is spreading abroad the natural products of the world without limits as to temperature. As a means of storing foodstuffs, it is providing a safeguard against any local disaster that would inflict a shortage on a community. It gives to us the realisation of the benefits of laying up the surplus from the plentiful harvest for the inevitable shortage that comes.

I would like to think that I have made my younger friends in the Institute feel that they are associated with a great industry which has still within itself vast stretches of undiscovered possibilities. To them is the satisfaction of knowing that in their hands lies an opportunity which provides unlimited scope for all the knowledge they can acquire and for abundant research.

I feel confident that what has been done during the past fifty years is no more than a foundation upon which the present and future generations can build a nobler structure.

# RESEARCHES INTO THE STRUCTURE OF ALLOYS.\*

By A. J. BRADLEY, F.R.S. (ASSISTANT DIRECTOR OF RESEARCH, CAVENDISH LABORATORY, CAMBRIDGE), W. L. BRAGG, F.R.S. (CAVENDISH PROFESSOR OF EXPERIMENTAL PHYSICS, CAMBRIDGE), AND C. SYKES, D.Sc. (RESEARCH DEPARTMENT, METROPOLITAN-VICKERS ELECTRICAL CO., LTD., MANCHESTER).

(Figs. 20 to 23 = Plates I. to IV.)

## SUMMARY.

The paper describes a body of related researches which have been carried out in the last few years.

Part I. deals with the investigation of equilibrium diagrams by means of X-ray analysis, in particular the analysis of binary and ternary diagrams with the component metals chromium, iron, cobalt, nickel, copper and aluminium. Structures of submicroscopic order of magnitude and the theory of the order-disorder transformation are also reviewed.

Part II. deals with the experimental investigation of the order-disorder transformation, using the alloys of  $\beta$ -brass,  $\text{Cu}_3\text{Au}$ ,  $\text{Cu}_3\text{Pd}$  and  $\text{Ni}_3\text{Fe}$ . The values found for the energy of the transformation are in satisfactory agreement with those predicted by the theoretical treatments given by Bragg and Williams, Bethe and Peierls. The thermal methods specially developed for the above investigation have also been employed to determine the specific-heat/temperature curves of iron, nickel and a number of age-hardening alloys. The results obtained from consideration of these curves are recorded.

## INTRODUCTION.

By W. L. BRAGG, F.R.S.

FOR the last three years the British Iron and Steel Federation has supported certain researches into the structures of metals and alloys by the methods of X-ray analysis. A special panel, the "Structure of Alloys Research Panel," was formed—consisting of the following :

Dr. W. H. Hatfield	.	Brown-Firth Research Laboratories.
Dr. A. McCance	.	Messrs. Colvilles, Ltd.
Dr. T. Swinden	.	The United Steel Companies, Ltd.
Mr. E. C. Evans	.	<i>Secretary</i> , Iron and Steel Industrial Research Council.

—to receive reports of the work, which has been carried out under my general supervision, and generally to discuss the implications and assist in achieving co-ordination with practical metallurgy. Dr. Bradley, Dr. H. Lipson and their collaborators have been especially concerned with the investigations of atomic arrange-

\* Received February 29, 1940.

ment in alloys, which have been carried out at Manchester University, at the National Physical Laboratory and now at the Cavendish Laboratory, Cambridge. Dr. Sykes, of Metropolitan-Vickers, has dealt with physical properties of structures the atomic arrangements of which had been established, such as specific heat, electrical resistance and rate of attaining equilibrium. A detailed account of the investigations may be found in the papers which have been published during the course of the investigations, of which a list is given below. It is the purpose of the present report to summarise the results, and to indicate the relation of the work which has been done, and that which it is proposed to do, to some of the outstanding problems concerning the properties and behaviour of materials used in industry.\*

At the risk of repeating a story which has often been told, it is perhaps justifiable to indicate the nature of the new line of attack on problems of metal structure, which has been made possible by X-ray analysis. Certain scientific methods of studying metals have long held the field, and their value has been so well established that no one would now challenge their usefulness in practical everyday problems. Chemical analysis is essential, because the mechanical properties of metals are influenced in a fundamental and complex way by even small proportions of certain elements, and in order to co-ordinate practical observations it is important to know which of these elements are present and their amounts. Metallography, the technique of studying polished and etched specimens under the microscope, was founded by Sorby and by Martens some seventy years ago, and led to a very great increase in our knowledge of the structure of metals. Thermal analysis has been used in conjunction with metallography to establish the effective temperatures for heat treatment and has facilitated the construction of equilibrium diagrams.

As compared with these classical methods, the application of X-ray analysis to metals is a very recent development. Sorby's work remained unnoticed for twenty years; the serious application of X-ray methods to metals has as yet not had half that time to show what it can do. Yet it is already clearly indicated that it will rank with the others as a method of fundamental importance which gives information of quite a new kind. It therefore seems to be very desirable that the exploration of its possible uses for industrial problems should be pushed forward as energetically as possible. Much of the pioneer work on the atomic patterns of crystals has been done in this country, in particular the extension

\* As will be seen from the acknowledgments in many of the papers referred to in the present account, Dr. Bradley's group have been engaged during the last few years on a parallel research into the magnetic properties of alloys. This research has been carried out for the Electrical Research Association, and the Permanent Magnet Association, and I should like to take this opportunity of acknowledging the generous support which we have received.



of X-ray analysis to very complex patterns. A scientific tradition has been built up, and a number of men have become experts in the technique, so that we are in a strong position to apply our scientific knowledge to practical problems.

The new information given by X-ray analysis may be summed up as follows. Metals and their alloys are crystalline, their atoms being arranged in regular patterns. X-ray analysis reveals the nature of the pattern, showing how the atoms are placed relatively to each other. It shows how the pattern varies from phase to phase when different compositions of an alloy system are studied. From the purely scientific point of view, the study of the atomic patterns of alloy phases is providing a new basis for metal-chemistry. The equilibrium diagrams of alloys of two metals have been thoroughly explored by the older metallurgical methods, but the new methods make possible an exhaustive study of alloys of three or more metals. This work is only in the initial stages; there are so many combinations, even if one restricts oneself to the common metals, that it will take a long time to survey the field. However, there are already indications of general laws, and of a theoretical explanation of the crystalline patterns which are formed when the metallic elements are alloyed in different proportions. As far as this goes, the story is very similar to that of the investigation by X-rays of inorganic compounds, minerals, organic compounds, textiles and other materials. The knowledge of atomic arrangement has cast a flood of light upon many old problems of the nature of chemical compounds; it is no exaggeration to say that in many cases, such as the structure of inorganic salts and of minerals, our ideas have had to be completely revised, and much simpler explanations and generalisations have replaced former ones.

The main problem of correlating the mechanical properties of metals with their structure is not solved, however, when we have analysed their crystalline patterns. This is made clear by the following consideration. A study of alloys by X-rays has revealed a large number of crystalline patterns, many of them exceedingly complex. Such complex structures are very interesting as material for a study of metal-chemistry, but the majority of them are brittle and useless for practical purposes. On the other hand, practically all metals and alloys used in industry have one or other of two simple crystalline patterns, which are known as "face-centred cubic" and "body-centred cubic." For instance, austenitic structures are face-centred cubic and  $\alpha$ -iron is body-centred cubic. Since these patterns are common to alloys which exhibit a wide range of different mechanical properties, we must look for some other feature of structure. X-ray analysis has already indicated the nature of this feature, described in the next paragraph.

The microscope can only reveal structure which is on a scale larger than that of the wave-length of light. Even when pushed to the extreme limit, when magnifications of 2500 are attained, the



details must be on a scale of  $10^{-4}$  cm. if they are to be seen. The crystalline pattern of the metals is on a scale of  $10^{-8}$  cm.; for instance, the distances apart of neighbouring atoms in the metals chromium, manganese, iron, cobalt, nickel, copper and zinc are between  $2.4 \times 10^{-8}$  and  $2.8 \times 10^{-8}$  cm. There is therefore a range of dimensions between the smallest structure visible under the microscope and the scale of the atomic pattern which is actually more extensive than the range between coarse structures visible to the naked eye and those which can be seen under the highest powers. X-ray analysis conveniently covers the lower range. It takes over just where the microscope can no longer be used, and carries us down to the scale of the atomic structure itself. Further, the structures which are found on the scale between  $10^{-4}$  cm. and  $10^{-8}$  cm. are probably of as much importance to the mechanical properties of the metal as the structures visible under the microscope. In most cases metals and alloys which have valuable mechanical and physical properties are neither in true equilibrium, nor structurally homogeneous, nor perfect crystals. A condition of complete solution of the constituents at higher temperatures may break up by incipient precipitation into regions of different composition, in a manner which depends on the rate of cooling or time and temperature of annealing. If we could increase the resolving power some hundred or thousand times, it would be possible to see that the smallest crystals visible under the microscope have further complex elaborations of structure. An alloy may break up, for instance, into alternate sheets of different composition, as described in A (5) of Part I., such phenomena being quite beyond detection by the microscope. By means of X-rays one can measure the spread and thickness of such sheets, and estimate their composition.

When the crystals of a metal are distorted by cold-work, they are broken up into a mosaic of minute crystals which are not in perfect alignment with each other. Very severe cold-work would appear to reduce the average size of the elements of this crystalline debris to between  $10^{-4}$  and  $10^{-5}$  cm. It will be noted that such dimensions are submicroscopic, and that it is fortunate that we are able to have recourse to X-rays to study the structure of such cold-worked material. The grain size, state of strain and preferred orientation of this interesting condition of the metal can be thus determined. Here we are considering the reason why cold-rolling, cold-drawing and like processes produce their valuable results, and it is very desirable to obtain a clear conception of the mechanism of such processes.

We are as yet unable to explain, even in a qualitative way, how the mechanical strength and other properties of a metal depend either on its structure as revealed by the microscope or on the finer structure inside the visible crystals which is revealed by X-rays. It is, however, well known that certain structures of steel seen

under the microscope are correlated with desirable mechanical properties, and that their presence is evidence of success in the treatment that the steel has had, whereas other structures indicate undesirable qualities. This is so much a matter of common experience that it is hard to realise that such knowledge is purely empirical, and that the properties of the material have in no way been "explained" when an investigator notes a particular structure and correctly infers the quality of the steel. The application of X-ray analysis is already building up a similar body of empirical knowledge, relating the small-scale structures to the bulk properties. There are certain difficulties inherent in the method. We can see structures through a microscope; they have to be inferred from the X-ray results by a rather laborious process of analysis. But experience and training enable an investigator to read an X-ray diffraction picture almost as surely as if he were looking at the actual structures.

In considering the question of mechanical strength, the peculiar nature of a metallic structure must be borne in mind. The atoms of the metal have no direct links one to another. They are held together by a system of electrons common to all the atoms, which can drift through the structure and so make it an electrical conductor. If we imagine a mass of positively charged shot permeated by a negatively charged fluid so that the attraction between shot and fluid holds the whole mass together, we have a working model which may serve as an illustration. The metal atoms can slither over each other, and if the structure is distorted by a relative movement of the atoms the wound can be healed again, leaving the structure as sound as before. In contrast to this, the atoms in such solids as quartz and diamond are bound by direct links, which, once broken, are not formed again. The characteristic ductility of a metal, its plastic flow along glide planes, its recrystallisation on annealing and the diffusion of one metal through another at temperatures far below the freezing point, are consequences of the peculiar nature of the metal structure. If the metal atoms can move freely past each other, why has a metal any strength at all? As is well known, the answer to this is that a perfect crystal of any pure metal has so little resistance to deformation that it is still an open question whether the elastic limit tends to zero as perfect purity and regularity are approached. Resistance to shear only exists when the perfection of the crystal is destroyed by cold-working, or when atoms of more than one kind are present. The easy glide along crystalline planes would appear to be blocked in some way by the irregularities due either to the cold-working or to the alloying. In other words, the strength of a metal is not a primary character of its inner crystalline structure, but a secondary character due to the relative orientation of the crystals of which it is composed, or to the ripple-like fluctuations in composition which are the result of heat treatment and have been described

above. Hence the sensitive response of the mechanical properties to heat treatment and the importance of studying the structures of a sub-microscopic character by X-rays and correlating them with mechanical properties. Hence also the grave difficulties, which have so far defied attempts to overcome them, of forming a satisfactory theory of mechanical strength since it is due to this complex secondary character. The influence on mechanical properties of adding various elements may be direct, in causing ripples in composition (*e.g.*, precipitation-hardening, the effect of carbon in steel). It may be indirect, in that the main function of the added elements is to vary the rate at which such structures are formed so that the necessary heat treatment becomes a practical possibility (as in many alloy steels). It may confidently be expected that the study of submicroscopic structures by X-rays will cast light on these problems. A knowledge of structure is essential if progress is to be made with the long-range research of establishing a satisfactory theory of mechanical strength. Quite apart from the final goal, the correlation of the structures with the bulk properties and the study of the effect of added elements on these structures may lead to the foundation of laws to guide the experimenter as to what elements to add and in what proportion to obtain desired modifications in mechanical or physical properties, and so be of immediate practical importance.

The researches described in the present report may be conveniently classified as follows :

(a) *Study of Phases Formed by Two, Three or More Metals.*—The object in this work has been to survey the different forms of phase structure formed when certain common metals are mixed in different proportions. The metals chosen for the investigation were iron, cobalt, nickel, chromium, copper and aluminium. There are twenty ternary diagrams to be investigated by taking these elements three at a time, and of them the following have been examined over all ranges of composition : Fe-Cu-Ni, Fe-Cu-Al, Fe-Ni-Al, Cu-Ni-Al, Fe-Ni-Cr, Fe-Ni-Co. A complete equilibrium diagram of a ternary alloy involves the establishment of the extent of the various phases at all temperatures. No attempt has been made to do this, or even to fix the precise boundaries of the phase areas at any one temperature. It has been judged more important to make a preliminary and rapid survey of all the various types of phase-pattern which may appear. The same rate of cooling, 20° C. per hr., has been used for all alloys, and it is estimated that the diagrams in this report represent a section of the equilibrium diagram at between 700° and 500° C., below which temperature practically no change takes place with the rate of cooling employed.

The equilibrium diagrams of two metals have been examined in much greater detail. They include Cu-Al, Co-Al, Cu-Ni, Ni-Al, Fe-Al, Fe-Ni, Fe-Cu, Cr-Al. Binary equilibrium diagrams have

been much studied by thermal and microscopical methods, and it is possible to compare the previous results with those obtained by X-rays. In some cases (*e.g.*, Cr-Al, Fe-Ni) the X-ray examination has suggested very profound modifications or extensions of the previous diagrams.

The same crystalline patterns recur in different alloy systems, and an important object of the work has been the identification and if possible the analysis of the many types. The face-centred cubic and body-centred cubic structures cover by far the most extensive ranges of composition and, as has been mentioned above, practically all useful alloys are found in these ranges. In addition, there are many highly complex phases, though the majority of these are modifications of one or other of these two simple structures, formed by certain atoms falling out of the structure with a consequent degradation in symmetry.

(b) *The Order-Disorder Transformation*.—Certain alloys solidify from the melt with their atoms arranged on a regular lattice, but with a quite random distribution of the atoms of either kind amongst the points of the lattice. At a temperature which may be hundreds of degrees below the melting point, what may be described as a "second crystallisation" sets in. The atoms rearrange themselves by exchanging places until the two kinds are in regular arrangement. The transformation differs from an allotropic change, because in the present case the same lattice points are occupied by the atoms before and after the change, whereas in an allotropic change one type of lattice turns into another. As an analogy, one may picture an array of regularly arranged boxes and an equal number of red and white balls. The high-temperature state is represented by filling the boxes with balls regardless of their colour, the low-temperature state by rearranging the balls till they form a chequer pattern of red and white. The transformation in  $\beta$ -brass, Cu-Zn, is an example. Now that the evidence for such a transformation is better understood, it has become clear that it takes place in many alloy structures.

Much work has been devoted to the study of this change, and an explanation is due of the importance which has been attached to it, although its direct bearing on the mechanical properties of alloys may not at first sight be clear. Its interest lies in its simplicity, which enables us to study in detail the movements of atoms in the solid. The change is governed by the relationship between the heat energy of the atoms, the difference in potential energy of the ordered and disordered states, and the "energy-barrier" which has to be overcome in order to cause two neighbouring atoms to exchange positions. The phenomenon provides a very pretty problem for the mathematical physicist, and has attracted the attention of some of the ablest in this country and abroad. The first crude theories only explained its course in a qualitative way, but the latest refinements of theory have been



very successful. Extensive experimental investigations have been made by Sykes. The change begins at a critical temperature, but is not complete until the temperature has been further lowered by several hundred degrees. Sykes has studied the degree of order at different temperatures, the output of energy as the change proceeds, the inception of order at nuclei when the critical temperature is reached, their subsequent growth, the effect on the electrical resistance, and the rate of relaxation towards equilibrium. These phenomena resemble the crystallisation of a solid from a liquid, or the growth of one solid phase from another, but they are much simpler because atoms only move from one point to another in a constant lattice. The order-disorder change is an interesting example of a metallurgical change, which has been very thoroughly examined experimentally, and which has received a satisfactory theoretical explanation. Though much remains to be done, the first chapter of the story has been completed, and attention is now being devoted to other problems.

In order to study the change, it has been necessary to construct precision apparatus for measuring the output or absorption of small quantities of energy during the transformation. The apparatus set up by Sykes for this purpose has proved to be very successful, and is now being used to study changes in energy in other transformations such as precipitation-hardening.

The investigations of equilibrium diagrams carried out by Dr. A. J. Bradley, Dr. H. Lipson and their collaborators are described in Part I. In Part II. Dr. C. Sykes has summarised the work which has been carried out under his direct supervision.

## **Part I.—Investigation of Equilibrium Diagrams and Theory of Order-Disorder Transformation.**

BY A. J. BRADLEY, F.R.S., AND W. L. BRAGG, F.R.S.

### **A.—X-RAY ANALYSIS OF EQUILIBRIUM DIAGRAM.**

#### *(1) X-Ray Technique.*

The powder method has been used throughout in the investigations on alloy phases. A small ingot of the required composition is made up, and a sample of the alloy is obtained in powdered form. The sample is placed at the centre of a flat cylindrical camera, around the rim of which a photographic film is placed. An X-ray beam from an appropriate anticathode is admitted as a narrow pencil by a slit system on one side of the camera, and falls on the specimen. The beams diffracted by the powder are recorded by the photographic film, their traces being arcs of varying curvature



as seen on the photographs in Fig. 2. The phases are recognised and their structures analysed by means of the characteristic pattern of diffracted arcs or "lines," as they are generally called, which each produces.

The impurities in the metals used have not exceeded 0.05%.\* As the work has been a preliminary survey, where the highest accuracy is not intended, the compositions are based on the quantities of material used in making up the alloy. Analytical checks indicate that the quoted compositions are accurate to about 0.5% (atomic). Thirty-gramme melts are made in a high-frequency induction furnace with a small pressure of hydrogen, in a crucible lined with alumina. The hydrogen is pumped off before solidification, and the alloys are allowed to cool *in vacuo*. They are lump-annealed for several days at a temperature not far below the melting point, to ensure homogeneity. About 0.1 g. of powder is prepared by filing or crushing in a mortar, and this is introduced into a small silica tube, which is sealed off. The standard treatment has been to cool the powder from 900° C. to room temperature at 20° C. per hr., which removes the effects of cold-working. It is estimated that the final state of the alloy is characteristic of equilibrium at between 700° C. and 500° C. In some cases the more direct method was used of keeping the alloy at an elevated temperature, for instance 600° C., for several days and then quenching.

A typical camera is shown in Fig. 1. The specimen of powder is mounted on a hair, suspended at the centre of the camera with a small weight to keep it plumb, and rotated during the exposure. About 10 mg. of powder are used; this is mixed with canada balsam and formed into a rod about 0.4 mm. in dia. and 1 cm. in length around the hair. In Fig. 1 (a) the X-rays enter through the slit system on the left. After falling on the specimen, the direct beam passes out of the camera by a window; radiation scattered back by the window is prevented from fogging the film by the trap to be seen on the right. Fig. 1 (b) shows the inner part of the camera around the edge of which the film is fixed by bands. Fig. 1 (c) shows the light-tight case which fits over the inner camera, with a mechanism for transmitting rotation to the specimen. Fig. 1 (d) shows the slit system, and Fig. 1 (e) a damping mechanism for stopping oscillation of the specimen when it is being centred. The mechanism for centring and rotating the specimen is reproduced in greater detail in Fig. 1 (f).

The ends of the film lie behind two knife-edges (shaded in the figure). The positions of these edges are accurately defined on the film because the part behind them is shielded from scattered radiation. The positions of diffracted beams from the powder at the centre which are turned back through nearly 180° from the direc-

\* With the exception of the chromium used in the Fe-Ni-Cr ternary alloy. The best material available when this research was carried out had 1% impurity.

tion of the incident beam, and so fall near these knife-edges, are extremely sensitive to small changes in lattice spacing of the crystalline pattern. By measuring accurately (to 0.01 mm.) the

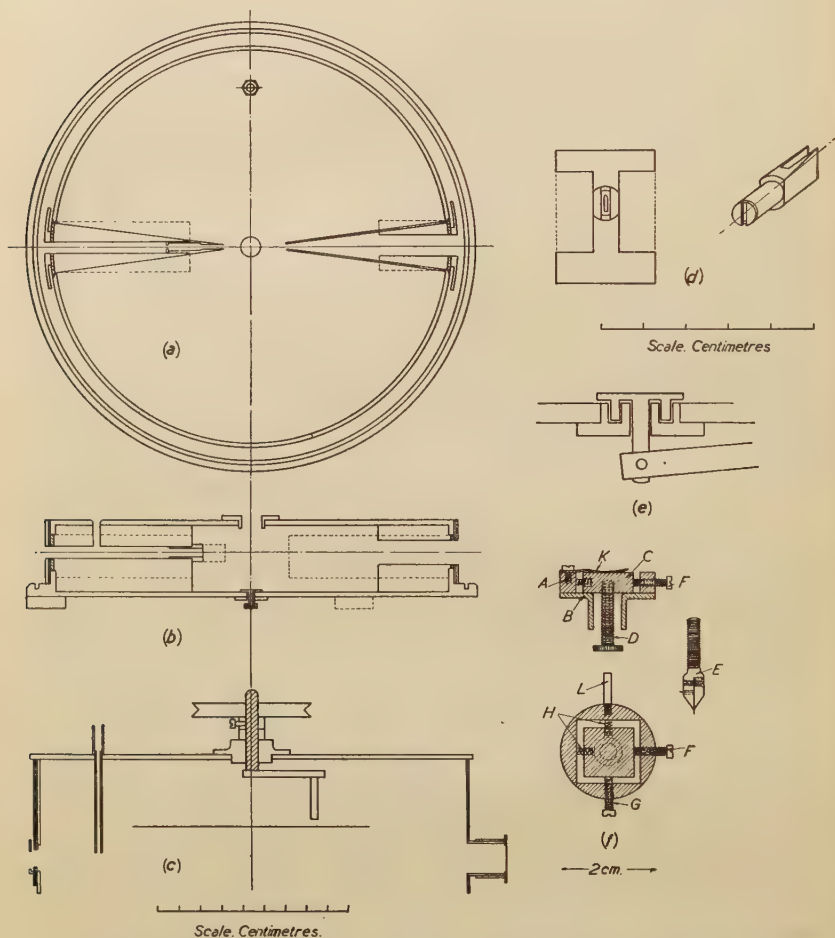


FIG. 1.—(a) Horizontal section of powder camera. (b) Vertical section. (c) Light-tight cover of camera. (d) Slit system. (e) Damping device. (f) Centring and rotation device.

distance between knife-edge and diffracted beam, it is possible to attain an accuracy in lattice-spacing measurement of the order of one part in 20,000, or even one part in 100,000 if the perfection of the crystalline structure permits. This is a very important feature

in the analysis of equilibrium diagrams. Cameras 9 cm., 19 cm. and 35 cm. in dia. have been used. A larger camera gives higher accuracy and greater resolution of the diffracted beams, but necessitates a longer exposure. The exposure time varies with the specimen, but is approximately 8 min., 1 hr. and 5 hr. for cameras 9 cm., 19 cm. and 35 cm. in dia., respectively.

It has been thought worth while to refer to some of these details, in order to emphasise the importance of the design of the camera. The principle is simple, but attention to detail in design produces a very striking improvement in the clarity of the photographs and the amount of information which they yield. There is as much difference between the photographs which were obtained with the first models and those which can now be got, as between ordinary photographs taken with a cheap camera and those got with a first-class lens. The slit system in particular is the result of much research. Its height, width and the shape of its bore are all a matter of careful adjustment. X-rays scattered in the bore of the slit must all be caught by the trap. Height and width must be small enough to give accurate results and good resolution, but not so small as to increase inordinately the time of exposure.

The diffracted beams in the photographs, examples of which are shown in Fig. 20, are produced by the  $K_\alpha$  doublet from various anticathodes in the X-ray tube. The  $K_\alpha$  doublet consists of two monochromatic components of slightly different wave-length. In addition, each anticathode gives a  $K_\beta$  component and a general spectrum of a wide range of wave-lengths. It is possible to suppress the  $K_\beta$  component and much of the general radiation by passing the rays from the X-ray tube through a suitable screen or "filter," this being either a thin metallic sheet or a layer of a metallic compound on a film. The anticathodes used are zinc, copper, nickel, cobalt, iron, manganese and chromium. It is necessary to suit the anticathode to the alloy under examination for two reasons. In the first place, the X-rays for a given metal as anticathode are absorbed very strongly by metals just below the anticathode-metal in the periodic table. Hence an alloy containing such metals gives a weak diffraction pattern owing to the absorption, and in addition the energy of the absorbed radiation is converted into scattered radiation of greater wave-length which fogs the film. For instance, a copper anticathode gives excellent results with brass, but very poor films with alloys containing iron or cobalt. In the second place, the positions of the diffracted beams depend on the wave-length, and by adjusting it one can bring a beam into the sensitive position near the knife-edges mentioned above, which enables lattice-spacing measurements of the highest accuracy to be made. The X-ray tube is a continuously evacuated type made by Metropolitan-Vickers, and it is possible to substitute one anticathode for another easily and rapidly.

A list of anticathodes, corresponding wave-lengths, materials

of the absorption screen and appropriate mass per sq. cm. to reduce the ratio  $K_\beta/K_\alpha$  to 1/600 is given in Table I.

TABLE I.—*List of Anticathodes, Corresponding Wave-Lengths, Materials of Absorption Screen, and Appropriate Mass per sq. cm. to Reduce the Ratio  $K_\beta/K_\alpha$  to 1/600.*

Target and Atomic Number.			$K_{\alpha_1}, K_{\alpha_2}$ in X Units.	Screen.	Mass. G. per sq. cm.
Zinc	30	.	1432.17 1436.03	Copper	0.021
Copper	29	.	1537.395 1541.232	Nickel	0.018
Nickel	28	.	1654.50 1658.35	Cobalt	0.016
Cobalt	27	.	1785.29 1789.19	Iron	0.014
Iron	26	.	1932.076 1936.012	Manganese	0.013
Manganese	25	.	2097.51 2101.49	Chromium	0.0115
Chromium	24	.	2285.03 2288.91	Vanadium	0.0105
Calcium	20	.	3351.69 3354.95	Tin	0.0015

The  $K_\alpha$  doublet ( $K_{\alpha_1}$  and  $K_{\alpha_2}$ ) is evident on the films as a doubling of the lines in regions where resolution is high. This doublet is a very troublesome feature. It is becoming increasingly important to study the structure of individual lines on the film which may be sharp and narrow or broad and diffuse, single or broken into groups or accompanied by satellite lines. Such details are obscured by the overlapping of components from  $K_{\alpha_1}$  and  $K_{\alpha_2}$ . The wave-lengths are too close for the elimination of one component to be effected by a screen, as in the case of  $K_\beta$  and  $K_\alpha$ . Experiments are now being made to test whether the separation can be effected by using as the incident X-ray beam one which has already been reflected by a crystal, but the closeness of  $K_{\alpha_1}$  and  $K_{\alpha_2}$  makes this difficult.

In order to study complete equilibrium diagrams, and to follow changes in the structure of an alloy as the temperature is altered, it is very desirable to be able to examine specimens at elevated temperatures. The design of a high-temperature camera presents certain difficulties which have not yet been fully overcome. The first work of this kind was done by Westgren, who used an iron



wire heated by an electric current as specimen and followed the  $\alpha$ - $\gamma$ - $\delta$  changes of lattice. When one wishes to extend the method to powdered alloys of all kinds, and to obtain accurate results, a number of conditions have to be satisfied. The temperature of the specimen must be uniform, or the lines will be diffuse because different parts of the specimen have undergone thermal expansion to a different extent. It must therefore be almost completely surrounded by a furnace so that it is effectively in a constant-temperature enclosure, with only a narrow slit to allow the incident and diffracted X-rays to pass.

Although the furnace, which may be at a temperature of  $1000^{\circ}\text{C}$ . or more, is only a few centimetres distant from the film, the latter must be so efficiently water-cooled that its temperature does not rise. The thermal insulation must therefore be very good. It is necessary to seal the powder in a tube in order that its composition may not be changed by evaporation. The tube must be able to withstand the temperature, and at the same time be so thin-walled that it does not absorb the radiation too much. In the high-temperature camera designed by Hume-Rothery this is effected by sealing the specimens in thin-walled silica capillaries. A new type of high-temperature camera has been made, and is now undergoing test. If it proves to be successful it will be possible to establish equilibrium diagrams with much greater completeness.

## (2) *Analysis of the Powder Photographs.*

It would be out of place to enter into the intricacies of X-ray analysis in this paper, but it may be worth while to indicate by a few examples the nature and extent of the information which can be obtained when two metals are alloyed together in a series of varying proportions and the samples are photographed with the powder camera.

If light of a single wave-length (monochromatic light) falls upon an optical diffraction grating consisting of a number of regularly ruled lines, spectra are produced. These are called spectra of the first, second, third order when the corresponding path difference is one, two or three wave-lengths for the light scattered from successive lines of the grating. Light which goes straight through without deviation is the "spectrum of zero order." The higher the order, the greater is the angle through which the light is bent or diffracted. Now, in a crystal there is a regular repeat of the pattern in all three dimensions, not in only one direction, as in an optical grating. The pattern repeats from right to left, up and down, and from back to front. When a beam of monochromatic X-rays falls at a suitable angle on the crystal, it forms a spectrum like the grating. We can no longer talk of first, second and third orders, however, but must give *three* indices to every order to correspond to the repeat of the pattern in three dimensions. These indices,  $hkl$ , are the path differences in wave-lengths for the light



scattered by any point of the pattern and the corresponding point to the right, that above it, and that behind it. We must speak of the spectrum 111 or 200, for example. Each line in a powder photograph is to be labelled with a set of these indices. All the minute crystals in the powder which are so orientated as to give a 111 spectrum, for example, bend the X-ray beam through a definite angle and produce a halo, part of which is intercepted by the film and shows up as a line across it. Each photograph in Fig. 20

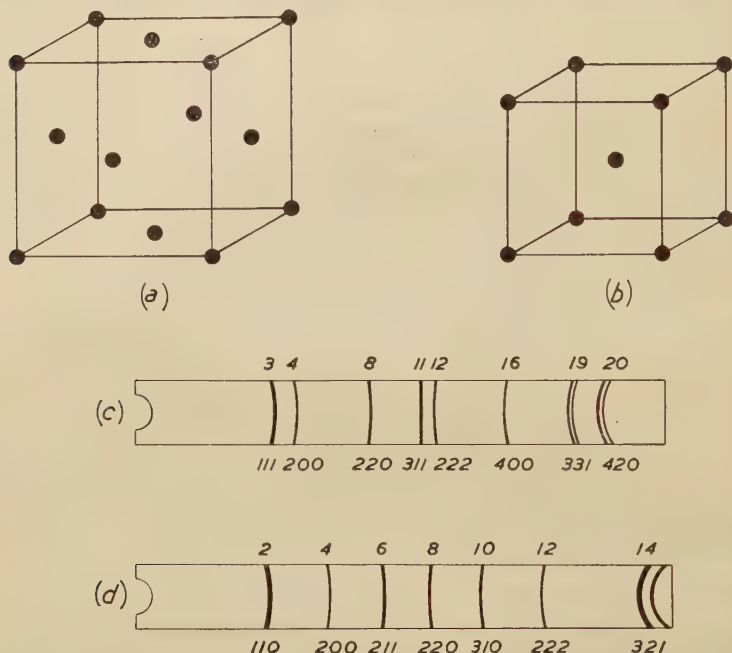


FIG. 2.—(a) Face-centred cube. (b) Body-centred cube. (c) Face-centred cubic powder photograph. (d) Body-centred cubic powder photograph.

represents a film which has been wrapped round one-half of the camera, the nick on the left being cut to allow the X-rays to escape from the camera and the sharp edge on the right being made by the knife-edge, as explained in the previous section. The lines on the left are spectra of low order diffracted through small angles, those on the right the spectra of higher order.

Two types of atomic pattern are very frequently encountered, the face-centred cubic structure and the body-centred cubic structure. They are shown in Figs. 2 (a) and 2 (b). The first has atoms at the corners and face centres of a series of cubes stacked together, the figure merely showing one of these cubes. The second has atoms

at the corners and centres of cubes. It is to be noted that there is no difference between the atoms at corners and face centres, or corners and cube centres. Any atom can arbitrarily be chosen as a corner, and when the cubes are based on it, the rest of the atoms fall into place; an example in Fig. 3 (*a*) makes this clear. It will be seen that the cubes in Figs. 2 (*a*) and 2 (*b*) are not the same size. They have been so drawn that the distance between nearest atoms is approximately the same in (*a*) and (*b*), as would happen in an allotropic change or when one phase succeeds another. For instance, (*a*) might represent austenitic iron and (*b*) ferritic iron.

These simple structures give correspondingly simple powder photographs, shown in Figs. 2 (*c*) and 2 (*d*). The indices,  $h k l$ , of the spectra which produce each line are shown below the film. The number on top of the film is  $(h^2 + k^2 + l^2)$ , so that 111 is numbered 3 ( $1^2 + 1^2 + 1^2$ ), 200 is numbered 4 ( $2^2 + 0^2 + 0^2$ ) and so forth. When a wave-length  $\lambda$  falls on a cubic structure with cube edge  $a$ , the diffracted beam ( $h k l$ ) is bent through an angle  $2\theta$  given by :

$$\sin \theta = \sqrt{h^2 + k^2 + l^2} \cdot \lambda / 2a$$

so that the angle only depends on  $(h^2 + k^2 + l^2)$  as far as the indices are concerned and increases with this number. It is therefore convenient to index the successive lines 1, 2, 3, 4, &c. Certain lines are always missing; for instance, it is not possible to make up 7 or 15 by the sum of three squares. A face-centred lattice gives the lines . . 3 4 . . 8 . . 11 12 . . 16 . . 19 20, &c., the dots representing lines which are missing because by optical principles  $h, k, l$  must all be odd or all even. In the body-centred lattice, on the other hand, the laws of optical interference decree that  $h + k + l$  must be even. The photograph therefore shows the lines . 2 . 4 . 6 . 8 . 10 . 12, for if  $h + k + l$  is even,  $h^2 + k^2 + l^2$  must also be even. The bottom photograph in Fig. 20 is typical of the face-centred lattice, the lines from left to right being 3, 4, 8, 11, 12, 16, 19 and 20 in alternate pairs and singles. If we neglect certain faint lines the origin of which is explained below, the photograph labelled  $\beta$  in Fig. 20 is typical of a body-centred lattice with lines 2, 4, 6, 8, 10.

The above applies to a simple lattice where all the atoms are the same. Fig. 3 shows what would happen if one kind of atom were at cube corners and another kind at cube centres. This arrangement shown in Fig. 3 (*c*) produces the photograph shown in Fig. 3 (*d*). The strongest lines are the lines 2, 4, 6, &c., of the body-centred lattice, but in addition faint lines appear which do not obey the rule that  $h + k + l$  must be even, this rule only holding when the centre is exactly the same as the corner. The succession is thus : 1 (faint), 2 (strong), 3 (faint), 4 (strong), 5 (faint), 6 (strong), 8 (strong), 9 (faint), 10 (strong). Line 7 is missing, because  $h^2 + k^2 + l^2$  cannot be 7, as explained above.

Fig. 3 also illustrates how an "order-disorder" change may be recognised. If the points of the lattice are occupied by two kinds of atoms, but the atoms are arranged at random (Fig. 3 (b)), so that as many of either kind are at cube corners as at cube centres, only the lines of the simple cube-centred lattice appear. If the atoms of one kind are all at corners and of the other all at centres (Fig. 3 (c)), the extra faint lines appear. When the change from disorder to order takes place, it is marked by the faint lines (superlattice lines) showing up where nothing existed before. The photograph changes from Fig. 2 (d) to Fig. 3 (d).

If we now consider the whole series of photographs in Fig. 20, it illustrates many points. Starting from the bottom, pure nickel,

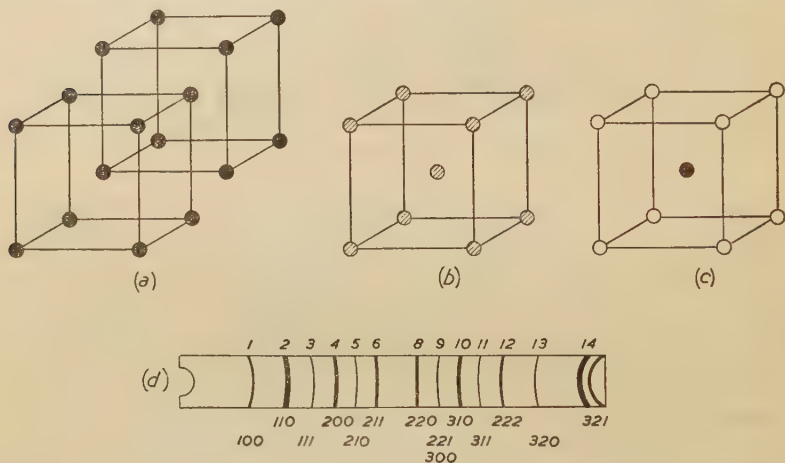


FIG. 3.—(a) Interpenetration of body-centred cubic lattices. (b) Body-centred cube with atoms in disorder. (c) Body-centred cube with ordered structure. (d) Powder photograph of ordered body-centred cube.

the structure is a simple face-centred cubic lattice. The lines on the right are double; this is the  $K_\alpha$  doublet, which is resolved because the dispersion is so great at high angles. The next photograph shows by its two sets of lines that *two* face-centred structures of slightly different lattice spacing exist side by side.  $\alpha$  is a simple face-centred lattice like nickel, but with a slightly larger lattice spacing, as shown by its lines occurring at slightly smaller angles. It is, in fact, nickel with a little aluminium in solution which has expanded the nickel lattice. The nature of  $\alpha'$  is clear from the photograph of 75% of nickel, 25% of aluminium (atomic). It is a face-centred lattice, but one can see certain additional faint lines. The order is: 1, 2 (faint), 3, 4 (strong), 5, 6 (faint). These extra lines, as in the body-centred case explained immediately above, are due to

a regular arrangement of the aluminium atoms at cube corners and nickel atoms at face centres, another type of "superlattice." For such an arrangement to be perfect, there must be three atoms of one kind at face centres for each atom of the other kind at corners, corresponding to the composition  $\text{Ni}_3\text{Al}$ . We deduce that certain compositions between 100% and 75% of nickel break up into two face-centred structures  $\alpha'$  and  $\alpha$ , the first taking most of the available aluminium to form a superlattice  $\text{Ni}_3\text{Al}$ , the other being nickel with a little aluminium dissolved in it.

There is a jump in the positions of lines between the third and fourth photographs from the bottom, because the wave-length has been changed from copper  $K_\alpha$  to the longer cobalt  $K_\alpha$ , with the object of bringing lines near the end of the film and facilitating measurement of lattice spacing. Corresponding lines therefore appear at greater angles. The  $\beta$  lattice which follows after the  $\alpha$  lattice is body-centred and ordered, as explained above. Its single-phase region is near the 50% composition, corresponding to  $\text{NiAl}$ .

The  $\delta$  phase is obviously more complex, from the number of lines which appear. The strongest lines, however, will be seen to correspond to those of the  $\beta$  body-centred structure, although single lines of the latter become groups of lines in the case of  $\delta$ . Analysis shows that the  $\delta$  structure is, in fact, a distorted form of the  $\beta$  structure. It appears as the only phase in the neighbourhood of the composition  $\text{Ni}_2\text{Al}_3$ . The structure may be described by starting with aluminium atoms at cube corners and nickel atoms at cube centres as in  $\beta$ , removing one third of the nickel atoms, and slightly distorting the resulting structure along a trigonal axis. The point to emphasise, without going too far into detail, is that the photograph shows immediately that  $\delta$  is a distorted form of  $\beta$ .

$\epsilon$  is a complex orthorhombic phase, which has been analysed. The very large number of lines is characteristic of structures of orthorhombic or lower symmetry.  $\eta$  is the structure of aluminium itself, which is face-centred cubic like nickel. The scale of the aluminium structure is greater than that of the nickel structure, but this is almost counterbalanced by the change from copper to cobalt radiation. The first and last photographs are therefore very similar.

It will be noted that  $K_{\alpha_1}$  and  $K_{\alpha_2}$  are superimposed on the left-hand side of each film, but are clearly separated when a line is near the right-hand edge. This is so because a very small difference in wave-length makes a large difference in angle when  $2\theta$  is near  $180^\circ$ . Conversely, a measurement of the angle from knife-edge to line leads to an extremely accurate value for the lattice spacing in this sensitive region of high dispersion. Since spacing in general varies with composition, a measurement of spacing tells us the composition of the phase producing it, even when it only exists in submicroscopic crystals dispersed amongst crystals of other kinds. This is one of the features of X-ray analysis which greatly simplifies the study of equilibrium diagrams.

The photographs shown in Fig. 20 are examples selected from the much larger series which was used to analyse the nickel-aluminium system. Compositions have been chosen which illustrate the successive single-phase and two-phase regions. The main points in using a series to establish the succession of phases are : (a) Each phase has its own characteristic pattern of lines ; (b) the position of the lines varies slightly in passing through an area of single phase, owing to change in composition affecting the lattice spacing ; (c) in a two-phase region, two patterns of lines are superimposed. They remain constant in position, but one set fades out, and the other

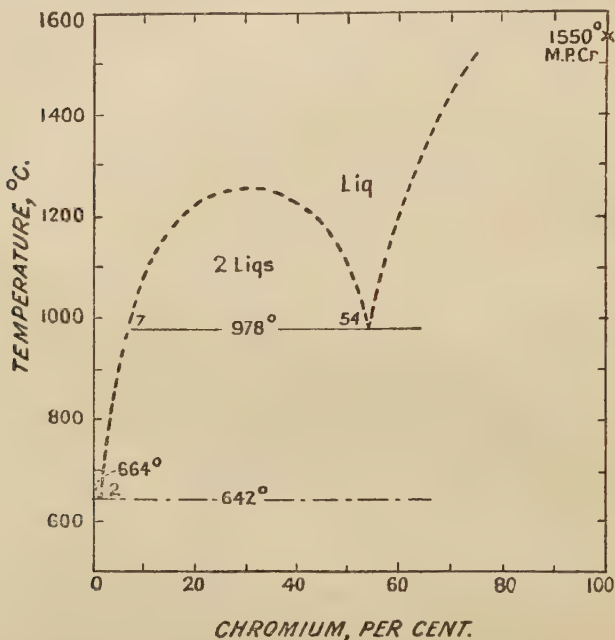


FIG. 4A (see FIG. 4B).—The Chromium-Aluminium System. From International Critical Tables (*Journal of the Institute of Metals*, 1937, vol. 60, p. 320).

comes into full strength as the two-phase region is traversed. All these points were made by Westgren in his original studies of phase diagrams. The main contribution of subsequent work has been to enrich our detailed knowledge of the structure of phase patterns, order and disorder, atoms missing from the lattice, partial precipitation and so forth.

### (3) Binary Equilibrium Diagrams.

The following brief notes on binary alloys summarise the information which has been obtained in the course of the present series of



investigations by X-ray analysis. There is no space here to refer in full to the work of other authors on which the investigations were based or which they supplement. Full references will be found in the papers which are quoted below. The investigation of the

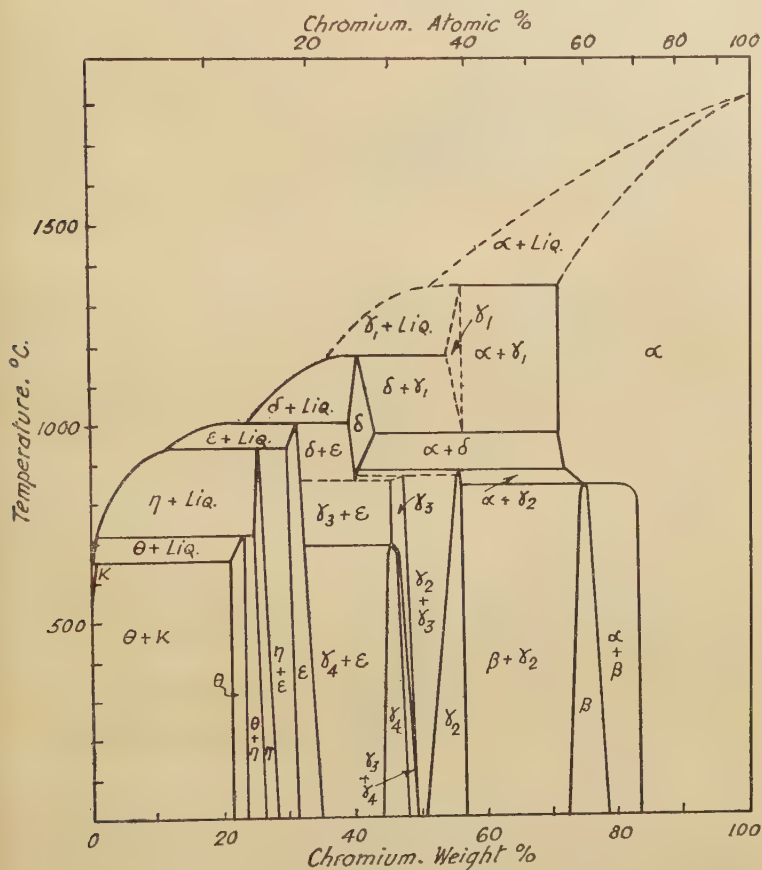


FIG. 4B (see FIG. 4A).—The Chromium-Aluminium System. From X-ray data.

binaries is a necessary preliminary to the study of the ternary diagrams described in the next section.

#### Chromium-Aluminium.

Fig. 4A shows the aluminium-chromium diagram given in the International Critical Tables, Fig. 4B a diagram based on the X-ray results.<sup>(1)</sup> It is not claimed that the latter is correct in detail, but the existence of the separate phases indicated in it has been proved and

the approximate ranges of temperature and composition at which they are formed have been outlined. It will be seen that the system is very rich in phases. The succession of phases is as follows :

$\alpha$ .—Chromium itself is body-centred cubic, and this phase may be regarded as a solution of aluminium in chromium.

$\beta$ .—Below  $850^{\circ}\text{C.}$ , and in the range between 72% and 78% of chromium, the  $\alpha$  structure turns into a tetragonal  $\beta$  structure. This resembles the  $\alpha$  body-centred structure, but the aluminium atoms, instead of being distributed at random, sort themselves out into sheets perpendicular to the tetragonal axis. The ideal structure would have one sheet of aluminium atoms to every two sheets of chromium atoms, with a composition  $\text{Cr}_2\text{Al}$ . This composition is, however, not quite within the phase-range of  $\beta$ .

$\gamma_1, \gamma_2, \gamma_3, \gamma_4$ .—This is a striking succession of phases which have similar structures based on the " $\gamma$ " type, which is found in so many alloy systems. The  $\gamma$  structure is a distorted form of the body-centred cubic lattice. If 27 of the unit body-centred cubes are stacked so as to form a large cube with cell-edges three times as great, there are 54 atoms to each of such large cubes. To arrive at the  $\gamma$  structure, the corner and centre atoms of the large cube are removed, leaving 52 atoms to the unit cell, and the positions of the remainder are adjusted to fill the gaps so created. A  $\gamma$  structure gives a complex powder photograph with the lines corresponding to those of a body-centred cubic lattice standing out more strongly than the rest. The  $\gamma$  structures of the chromium-aluminium system are all of this type, with slight variations in symmetry as the composition varies. In spite of their similarity, they are separated by definite two-phase regions.

$\delta, \epsilon, \eta$  and  $\theta$ .— $\delta$  has approximately the composition  $\text{CrAl}_3$ ;  $\epsilon$ ,  $\text{CrAl}_4$ ;  $\eta$ ,  $\text{Cr}_2\text{Al}_{11}$ ; and  $\theta$ ,  $\text{CrAl}_7$ .

$\alpha$ .—This is aluminium, which dissolves very little chromium.

Some of the phases only exist above  $850^{\circ}\text{C.}$ , and their range must be inferred by quenching the alloys from high temperatures. Even with a rapid quench partial decomposition is shown by the powder photographs, and the results above this temperature are in consequence uncertain. It is in cases such as this that an efficient high-temperature camera would be so very valuable.

### *Iron-Aluminium.*

The modifications of the iron-aluminium diagram suggested by the X-ray results are illustrated by Figs. 5A and 5B. Fig. 5A is the equilibrium diagram given by Ageew and Vher.<sup>(2)</sup> There is a large area, shaded in the figure, in which the structure is body-centred cubic, and which encloses the  $\gamma$  loop of face-centred cubic structure.  $\eta$  has approximately the composition  $\text{FeAl}_2$ ,  $\theta$  that of

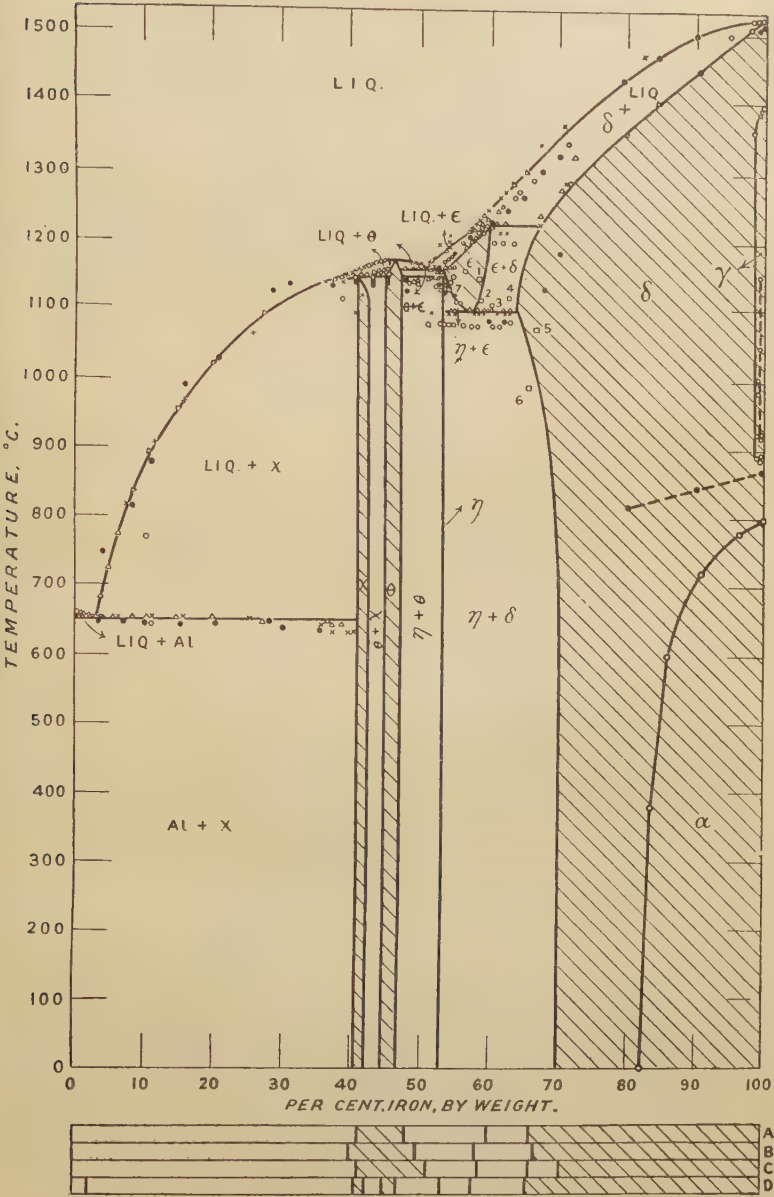


FIG. 5A (see FIG. 5B).—The Iron-Aluminium System. From Ageew and Vher (*Journal of the Institute of Metals*, 1930, vol. 44, p. 84).

$\text{Fe}_2\text{Al}_5$ , and  $\chi$  that of  $\text{FeAl}_3$ . In this diagram  $\chi$  ( $\text{FeAl}_3$ ) is shown as extending down to room temperature, but the X-ray results show that below about  $550^\circ \text{C}$ . it breaks up into  $\theta$  ( $\text{Fe}_2\text{Al}_5$ ), and a new phase with a narrow range, of approximate composition  $\text{Fe}_2\text{Al}_7$ . This modification of the aluminium-rich end of the diagram is shown schematically in Fig. 5B.

The large body-centred cubic phase region is by no means simple. Two types of superlattice are formed in this region. The simpler type has iron at cube corners and aluminium at cube centres with an ideal composition  $\text{FeAl}$ . When the aluminium content is less than this, the missing aluminium atoms at cube centres are replaced

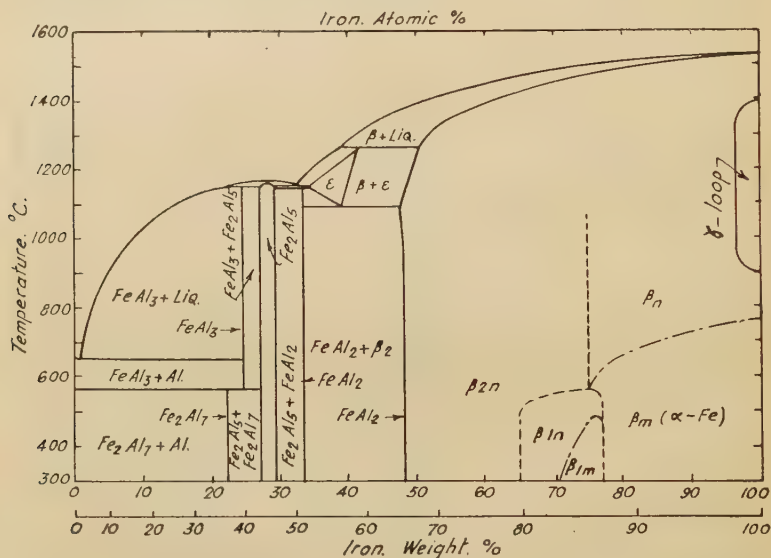


FIG. 5B (see FIG. 5A).—The Iron-Aluminium System. From X-ray data (Institute of Physics, Manchester Conference).

in a random way by iron atoms, and this continues as far as 25% of aluminium, 75% of iron (atomic). With still more iron there is a random distribution of aluminium atoms at cube corners and cube centres. Slowly cooled alloys, however, in the region  $\text{Fe}_3\text{Al}$ , show another type of superlattice.<sup>(3)</sup> In the ideal case of  $\text{Fe}_3\text{Al}$ , iron atoms occupy all cube corners, and aluminium atoms alternate cube centres, the remaining centres being occupied by iron atoms. These two types may be termed the  $\text{FeAl}$  and  $\text{Fe}_3\text{Al}$  superlattices. The course of the magnetic change point is indicated by the dot and dash lines in the figure. We thus have the regions shown in Fig. 5B :

$\beta_m$ .—Random distribution of iron and aluminium. Magnetic.

$\beta_n$ .—Random distribution of iron and aluminium. Non-magnetic.

$\beta_1m$ .— $\text{Fe}_3\text{Al}$  superlattice. Magnetic.

$\beta_1n$ .— $\text{Fe}_3\text{Al}$  superlattice. Non-magnetic.

$\beta_2n$ .— $\text{FeAl}$  superlattice. Non-magnetic.

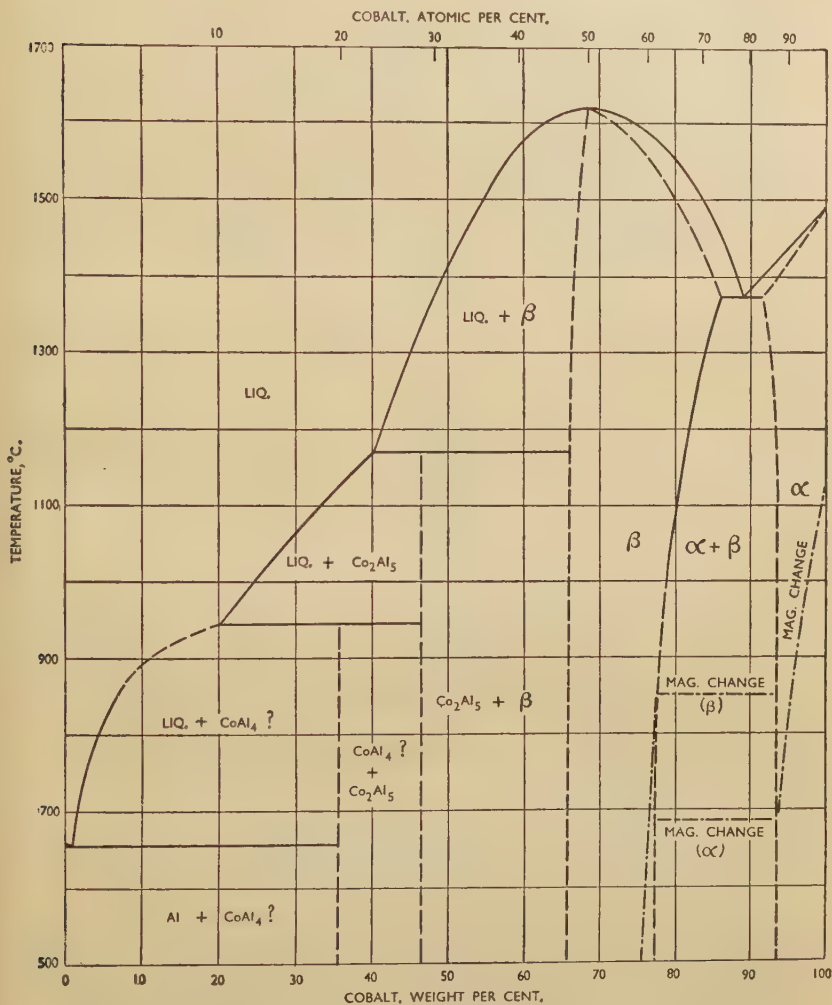


FIG. 6A (see FIG. 6B).—The Cobalt-Aluminium System. After Hansen (*Journal of the Institute of Metals*, 1939, vol. 64, p. 82).

The approximate boundaries between these regions are shown in the diagram. Attention was first drawn to these complex superlattice transformations by the complicated changes of electrical



resistance of iron-aluminium alloys when their heat treatment was varied.

### Cobalt-Aluminium.

Fig. 6A is due to Hansen.<sup>(4)</sup> Fig. 6B shows modifications based on the X-ray results.<sup>(5)</sup>

$\alpha$  and  $\epsilon$ .—The equilibrium is complicated in this region because cobalt exists in two forms.  $\alpha$ , face-centred cubic, is stable at higher temperatures and  $\epsilon$  (closely-packed hexagonal) at lower temperatures. Thermal analysis indicates that the change point is between 400° C. and 500° C., but the change to the hexagonal structure is very sluggish, and even after prolonged heating at temperatures below the change point a mixture of cubic and hexagonal forms is shown by the X-ray photographs. Aluminium is soluble in cubic cobalt

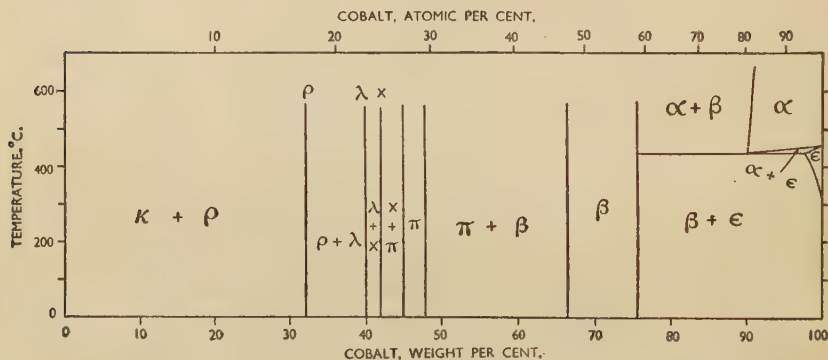


FIG. 6B (see FIG. 6A).—The Cobalt-Aluminium System. From X-ray data (*Journal of the Institute of Metals*, 1939, vol. 64, p. 83).

and not in hexagonal; it stabilises the cubic form at lower temperatures.

$\beta$ .—This resembles NiAl and FeAl, being body-centred with aluminium atoms at cube corners and cobalt atoms at cube centres. Like NiAl, on the cobalt-rich side, the number of cobalt atoms per unit cell is less than two, owing to vacancies at cube centres.

$\pi$ .—This is approximately  $\text{Co}_2\text{Al}_5$ . It has a hexagonal structure which has been analysed.<sup>(6)</sup>

$\chi$ ,  $\lambda$ ,  $\rho$ .—Between  $\pi$  and  $\lambda$  ( $\text{Co}_4\text{Al}_{13}$ ) another structure,  $\chi$ , appears, but it has so far been impossible to obtain it free from  $\pi$ .  $\lambda$  and  $\rho$  appear to have very narrow phase ranges.  $\rho$  occurs at  $\text{Co}_2\text{Al}_9$ .

### Nickel-Aluminium.

The X-ray results<sup>(7)</sup> suggest certain modifications of the phase equilibrium diagram published by Gwyer<sup>(8)</sup> (Fig. 7 (a)), these modifications being shown in Fig. 7 (b).

$\alpha$ .—There is a miscibility gap in the solid solution of aluminium in nickel, shown as  $\alpha + \alpha'$  in the figure. As explained above,  $\alpha$  is nickel with some aluminium in solution, and  $\alpha'$  approximates to  $\text{Ni}_3\text{Al}$ . An alloy quenched from  $1100^\circ\text{C}$ . shows no break into two phases which would indicate that the miscibility gap closes at high temperatures. The lattice spacing of the  $\alpha'$  phase behaves in an anomalous way. When the alloy is slowly cooled, the spacing exceeds  $3.58\text{ \AA}$ ., but alloys quenched from elevated temperatures

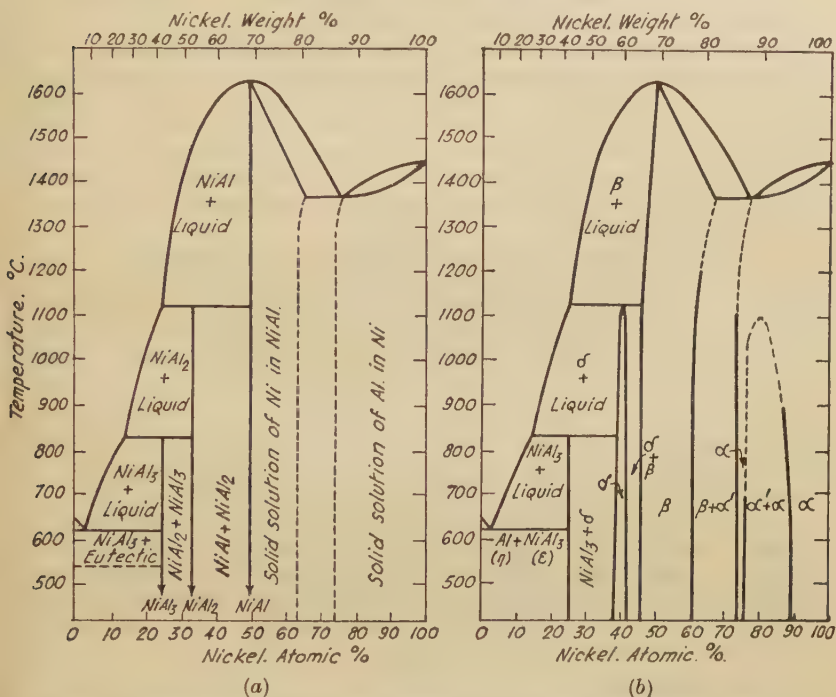


FIG. 7.—The Nickel-Aluminium System. (a) Gwyer's diagram. (b) From X-ray data (*Proceedings of the Royal Society*, 1937, vol. 159, p. 57).

have a spacing of about  $3.56\text{ \AA}$ . Even when the alloy is slowly cooled to  $100^\circ\text{C}$ . and then quenched, the spacing has the low value. The spacing of  $\alpha'$  also appears to vary in traversing the two-phase region; these anomalies have not yet been satisfactorily explained.

$\beta$ .—The  $\beta$  body-centred cubic region extends on both sides of the composition corresponding to  $\text{NiAl}$ ;  $\text{NiAl}$  itself has atoms of aluminium at cube corners and atoms of nickel at cube centres, as explained above. On the nickel-rich side of  $\text{NiAl}$ , the extra nickel atoms displace aluminium atoms at the cube corners, with a fall in lattice spacing owing to the smaller size of the nickel atom. On the

aluminium-rich side of  $\text{NiAl}$ , there is no converse effect of aluminium atoms displacing nickel atoms. Instead, all the aluminium atoms continue to be at the cube corners, while the cube centres are only partially occupied by nickel atoms. In other words, there are on the average less than two atoms per unit cell. In the limiting phase the number of atoms per unit cell drops to 1.84. In consequence the lattice spacing falls on the aluminium-rich side as well as on the nickel-rich side, being a maximum at  $\text{NiAl}$ .

There is a very striking series of changes in the appearance and fracture of the alloys in passing through the  $\beta$  region. Most alloys of nickel and aluminium resemble the parent metals in colour, but in this region the alloys assume a series of tints. The order, starting at the nickel-rich end, is yellow, pink, mauve-grey, green, blue, chromium-like and silvery. The nickel-rich alloys have a crystalline fracture, the aluminium-rich the conchoidal fracture characteristic of extreme brittleness. In fact, the 45% nickel, 55% aluminium alloy resembles the well-known  $\gamma$  structures which appear in many alloy systems.

$\delta$ .—The  $\delta$  phase,  $\text{Ni}_2\text{Al}_3$ , has already been described.<sup>(9)</sup> It is based on a body-centred cubic lattice, but one in every three of the sheets of nickel atoms perpendicular to a trigonal axis is left out. This process of dropping out nickel atoms begins in the  $\beta$  phase; it is as if the body-centred  $\beta$  structure can only exist as long as the number of random vacant positions in the lattice does not exceed a certain amount, and from that point there has to be a transition to the  $\delta$  structure where the vacant positions are regularly arranged. The powdered  $\delta$  alloys, unlike the other alloys of nickel and aluminium, are attacked by water with the evolution of hydrogen.

$\epsilon$ .—The  $\epsilon$  phase occurs at exactly  $\text{NiAl}_3$ , having no measurable range of composition on either side. It is a complex orthorhombic structure with sixteen atoms in the unit cell.<sup>(9)</sup> It is interesting as being one of the few cases, if not the only case, when a structure of orthorhombic symmetry and of a new type has been completely solved by the powder method alone.

### *Copper-Aluminium.*

The diagram in Fig. 8A is that given by Stockdale<sup>(10)</sup>; other workers have put forward diagrams which differ in certain details. The X-ray investigation has been particularly directed to clearing up doubtful points in the region between 16% and 29% of aluminium by weight. A comparison of the extents of the phases in slowly cooled alloys as indicated by X-ray analysis,<sup>(11)</sup> and those given by other workers, is shown in Fig. 8B.

$\alpha$ .—This phase is a solid solution of aluminium in the face-centred cubic copper lattice.

$\beta$ .—The  $\beta$  phase has a body-centred cubic structure, and a composition in the neighbourhood of  $\text{Cu}_3\text{Al}$ . If quenched, another type of pattern appears in the powder photographs, which is complex

but resembles the face-centred cubic type. The lines of this pattern are diffuse, like those of the martensitic structure formed on quenching austenite. The analysis of this new structure,  $\beta'$ , has not yet

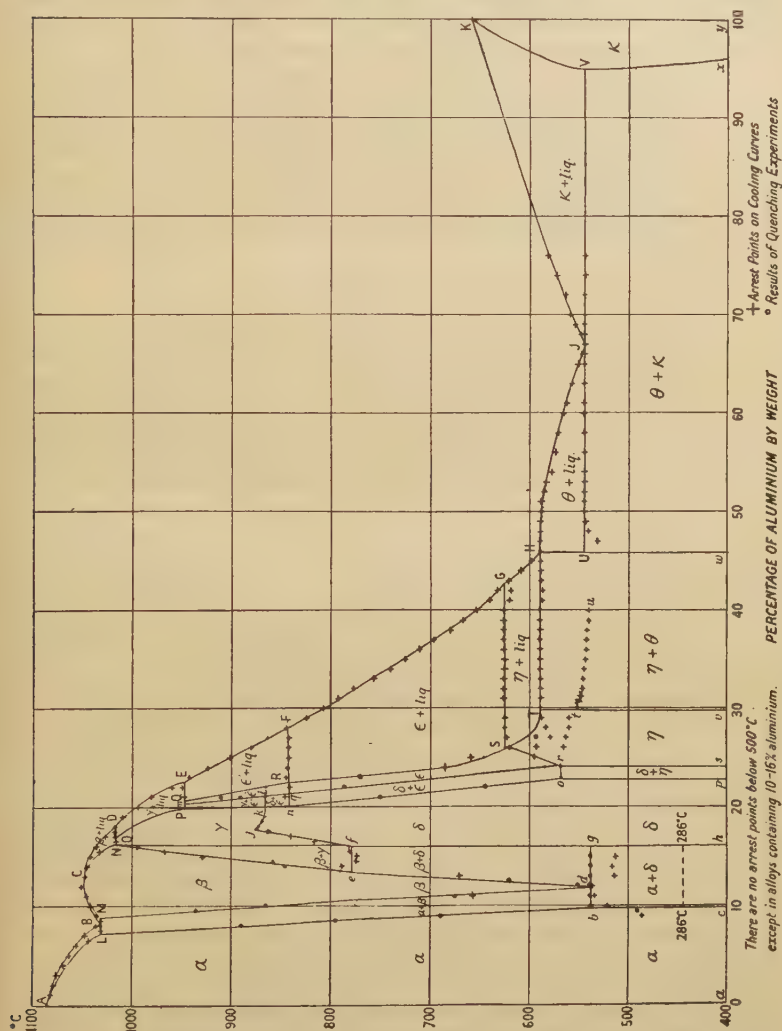


FIG. 8A (see FIG. 8B).—The Copper-Aluminium System, according to Stockdale's diagram (*Journal of the Institute of Metals*, 1924, vol. 31, p. 276).

been made. Slowly cooled alloys in this region break up into  $\alpha$  and  $\gamma$ .

$\gamma$ .—The alloy with from 16% to 19% of aluminium has a typical  $\gamma$  structure with 52 atoms in the unit cell, the composition approxi-

mating to  $\text{Cu}_9\text{Al}_4$ . Beyond 19%, atoms are lost from the structure and its symmetry degrades. The  $\gamma$ -like structures  $\gamma_1$  and  $\gamma_2$  which succeed  $\gamma$  appear to follow without any two-phase area between them, the photograph abruptly changing in passing from one to the other. The related alloys  $\gamma$ ,  $\gamma_1$  and  $\gamma_2$  cover Stockdale's  $\delta$  phase. They are followed by a definite two-phase region  $\gamma_2 + \zeta$ .

$\zeta$ ,  $\eta$ .—The  $\eta$  region of Stockdale's diagram appears to be more complex, the succession being  $\zeta$ ,  $\zeta + \eta$ ,  $\eta$ . Both structures are deformed types of the body-centred cubic lattice with missing atoms.  $\zeta$  is monoclinic with 21 atoms in the unit cell,  $\eta$  orthorhombic with 20 atoms in the unit cell. The number in each case if the lattice were simply body-centred would be 24.

$\theta$ .—This is tetragonal, with 12 atoms per unit cell, and a formula near  $\text{CuAl}_2$ .<sup>(12)</sup>

$\kappa$ .—This is a solution of copper in aluminium.

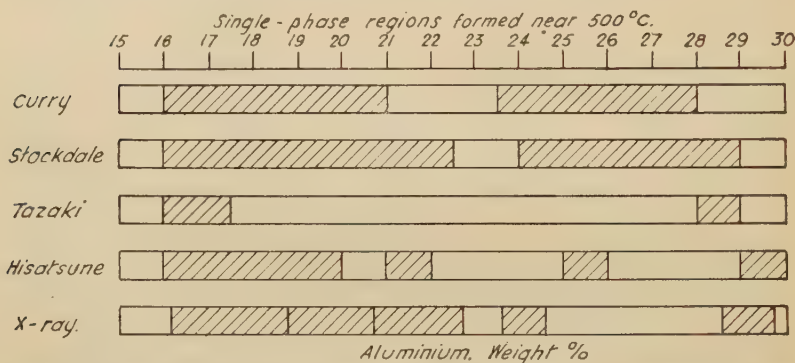


FIG. 8B (see FIG. 8A).—The Copper-Aluminium System. A comparison of phase regions near 500° C.

The sequence of phases is typical of alloys in this series containing aluminium. A face-centred cubic phase is followed by a body-centred cubic phase. Then follows a series of structures based on the body-centred lattice, but with an increasing number of atoms removed from the lattice, deformation to lower and lower symmetry, and more restricted ranges of composition. Finally there are one or more complex structures followed by aluminium itself.

#### Iron-Nickel.

The iron-nickel diagram, although the only phases are face-centred cubic ( $\gamma$ ) and body-centred cubic ( $\alpha$ ),\* presents peculiar difficulties, because equilibrium is so hard to establish. Although these difficulties are still far from being overcome, the X-ray results have made a suggestive contribution to their solution.

\*  $\alpha$  and  $\gamma$  are here used with the convention adopted for iron.



There is no difficulty when the nickel content exceeds 40%. The alloys are face-centred cubic, and this region extends towards the iron end at higher temperatures and finally includes  $\gamma$ -iron. Sykes has shown that  $\text{Ni}_3\text{Fe}$  has a superlattice,<sup>(13)</sup> iron atoms being at cube corners and nickel atoms at face centres of the unit cube. The boundaries on the right of Fig. 9A, due to Hanson and

## IRON-NICKEL ALLOYS

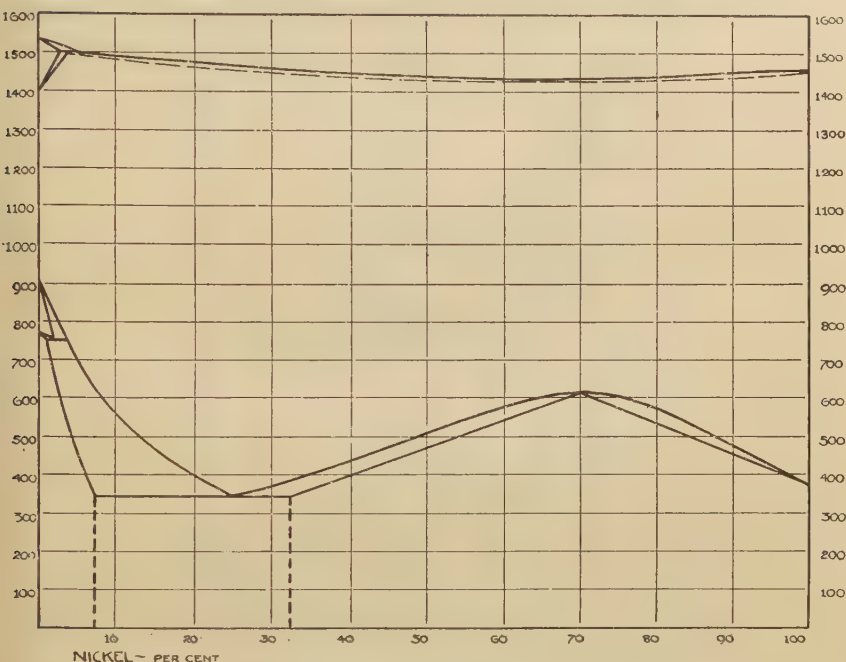


FIG. 9A (see FIGS. 9B and 9C).—The Iron-Nickel System, according to Hanson and Freeman (*Journal of the Iron and Steel Institute*, 1923, No. I., p. 301).

Freeman,<sup>(14)</sup> are from the ferromagnetic to the paramagnetic conditions, and not changes of structure.

At the iron end changes are extremely sluggish, and with ordinary rates of heating and cooling appear to show a considerable hysteresis. This hysteresis is indicated by the double lines in Fig. 9B, but the X-ray results confirm that no state of equilibrium between  $\gamma$  and  $\alpha$  can be represented by such a diagram.

A possible equilibrium diagram based on the X-ray results<sup>(15)</sup> is shown in Fig. 9C. There are two definite temperatures at which

reactions take place,  $580^{\circ}\text{C.}$  and  $350^{\circ}\text{C.}$  Below  $580^{\circ}\text{C.}$  there is a sudden very striking broadening in the two-phase gap, as shown by the figure. The region marked  $\gamma + \gamma'$ , indicating that  $\gamma$  separates into two alloys of different compositions, has not been established; the separation is suggested as a possible cause for the abrupt broadening of the two-phase region below  $580^{\circ}\text{C.}$  From  $580^{\circ}\text{C.}$  down to  $350^{\circ}\text{C.}$ ,  $\alpha + \gamma$  two-phase structures are formed at all compositions between 6–8 atomic-% of nickel and 23–26 atomic-% of nickel. The X-ray results definitely establish the extent of this two-phase range. The changes are very sluggish, many days being

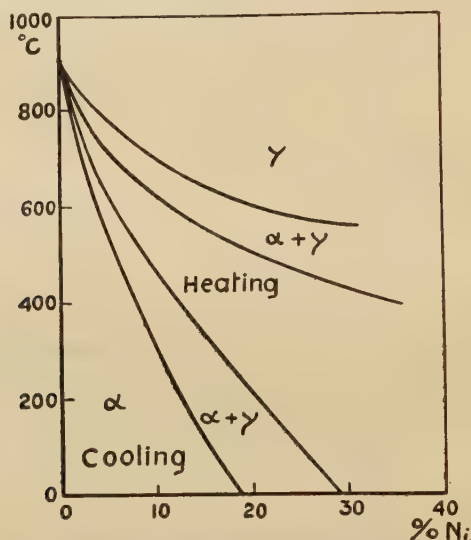


FIG. 9B (see FIGS. 9A and 9C).—The Iron-Nickel System, according to Honda and Miura (*Iron and Steel Institute*, 1936, *First Report of the Alloy Steels Research Committee*, p. 69).

necessary at  $570^{\circ}\text{C.}$  just below the critical temperature, and a time of at least six months at temperatures near  $350^{\circ}\text{C.}$  If the alloy is cooled through the region between  $580^{\circ}\text{C.}$  and  $350^{\circ}\text{C.}$ , without this long annealing, it shows only the lines of the  $\alpha$  (body-centred) structure.

The form of the diagram below  $350^{\circ}\text{C.}$  cannot be regarded as definitely established. The region marked  $\alpha_1$  is at the composition  $\text{Fe}_3\text{Ni}$ , and it is suggested that this is a superlattice structure. This suggestion is based on the fact that if the alloys between 5 and 25 atomic-% of nickel are rapidly cooled through the  $\alpha + \gamma$  region, they consist entirely of the  $\alpha$  structure, and the lines become sharper on annealing, as if this were the equilibrium structure. It is not

possible to get evidence of the two-phase  $\alpha + \alpha_1$  region, if it exists, because there is so little change of lattice spacing with composition.

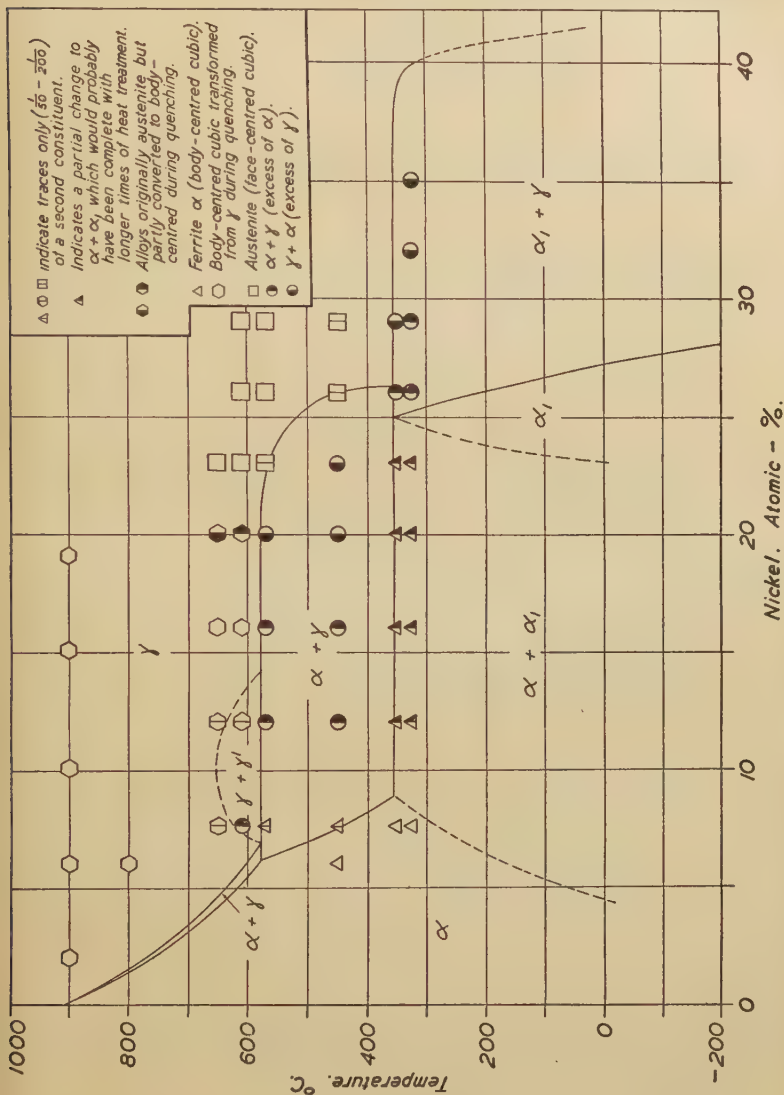


FIG. 9c (see Figs. 9A and 9B).—The Iron-Nickel System from X-ray data (*Journal of the Iron and Steel Institute*, 1939, No. II., p. 21P).

On the other hand, alloys beyond 25% change into  $\alpha + \gamma$  ( $\alpha_1 + \gamma$ ), and there is apparently no tendency on annealing for any part of the  $\gamma$  to go back to  $\alpha$ .

To sum up, the conditions differ according to the composition. There are four distinct ranges :

- (a) 0–6% of nickel.
- (b) 6–25% of nickel
- (c) 25–40% of nickel
- (d) 40–100% of nickel.

(a) The alloy changes from face-centred cubic at high temperatures to body-centred cubic at low temperatures. This has been checked by Smith<sup>(16)</sup> with a high-temperature camera.

(b) The alloys can be obtained at room temperature as single-phase or two-phase, depending on the heat treatment. To obtain the two-phase structure they must be heated for long periods between 580° C. and 350° C. If cooled rapidly the alloy is converted almost completely to a body-centred type.

(c) Alloys in this range are converted from  $\gamma$  to a mixture of  $\alpha$  and  $\gamma$  on cooling below 350° C. Many months are required to carry out this process to equilibrium, and normal rates of cooling only give the  $\gamma$  type. If the proportion of nickel is below 30%, the change from  $\gamma$  to  $\alpha$  can be effected by plunging the alloy in liquid air.

(d) The structure is  $\gamma$  (face-centred cubic).

This diagram is of particular interest with respect to the phases found in iron-nickel meteorites, and may suggest the conditions under which equilibrium in the meteorites has been established.

This system has been very thoroughly investigated by Owen and his co-workers.<sup>(17)</sup> His X-ray results are in substantial agreement with those described here, but he proposes a simpler equilibrium diagram.

#### *Iron-Chromium.*

Both iron and chromium are body-centred cubic, and, except in one limited region, they form a continuous series of solid solutions. This region is in the neighbourhood of FeCr, where a complex  $\epsilon$  phase appears at temperatures below about 900° C. Many observers have found evidence of this  $\epsilon$  phase, and its existence as a complex structure is confirmed by the X-ray powder photographs. It has not yet been analysed.

#### *Nickel-Chromium.*

Face-centred cubic nickel dissolves about 40% of chromium, and body-centred chromium dissolves about 2% of nickel, with a two-phase region between these compositions.

#### *Iron-Cobalt.*

The cobalt-rich end is complicated by the allotropic change of cobalt, which is face-centred cubic at high temperatures and

hexagonal close-packed at low temperatures. Hexagonal cobalt dissolves a small percentage of iron. There is then a two-phase region, followed by a solution of iron (up to about 10%) in cubic cobalt. From 25% of iron onwards the structure is body-centred cubic like  $\alpha$ -iron.

#### *Nickel-Cobalt.*

From nickel to 90% of cobalt, the structure is face-centred cubic. This is followed by a two-phase region, and then hexagonal cobalt with less than 3% of nickel in solution.

#### *Iron-Copper.*

Each metal dissolves less than 1% of the other, and there are no intermediate phases.

#### *Nickel-Copper.*

A complete range of face-centred cubic solid solutions exists.

### (4) *Ternary Equilibrium Diagrams.*

The X-ray methods developed to explore binary equilibrium diagrams are particularly well adapted to the examination of alloys formed by three or more metals. When there are three component metals, an alloy at a given temperature may consist of a single phase, a mixture of two phases or a mixture of three phases, depending on the composition. The powder photographs enable the phases present to be identified and their proportions roughly estimated. This latter possibility considerably lightens the labour of exploring the whole range of possible combinations. As will be seen from the examples given below, it is possible to outline the phase-areas by making up a relatively small number of alloy samples.

The fundamental features of ternary diagrams are illustrated by Figs. 10. Fig. 10A shows a simple case of three metals,  $A$ ,  $B$ ,  $C$ , where each metal dissolves a certain amount of the other two but no intermediate phases are formed by any combination. The compositions are represented by points in an equilateral triangle in the usual way. The point  $P$  represents amounts of  $A$ ,  $B$  and  $C$  proportional to the perpendiculars  $PX$ ,  $PY$ ,  $PZ$  in Fig. 10B. The proportions in the diagrams of ternaries are in atomic percentages, because this ratio, and not the weight percentage, is the significant one as regards atomic patterns. The regions marked  $\alpha$ ,  $\beta$ ,  $\gamma$  in Fig. 10A represent the ranges of composition for which a single phase is present; an alloy in the  $\alpha$  range, for example, has the structure of  $A$  with  $B$  and  $C$  dissolved in it. The two-phase regions are traversed by tie-lines; an alloy of composition  $Q$  breaks up into two phases the compositions of which are represented by the points  $X$  and  $Y$  at either end of the tie-line through  $Q$ . Any alloy along the line  $XY$  breaks up in the same way, the amount of  $X$  being pro-



portional to  $QY$  and the amount of  $Y$  to  $QX$ . An alloy  $R$  within the triangle  $X'Y'Z'$  breaks up into three phases the compositions of which are represented by the corners of the triangle.

Each diagram represents the state of the alloys at a given temperature, a third dimension being necessary if the variation of the equilibrium diagram with temperature is to be represented. Alternatively, a succession of triangles may be drawn to give sections of the three-dimensional figure at a series of temperatures.

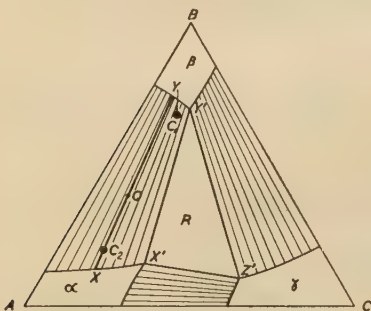


FIG. 10A.—A Ternary Equilibrium Diagram with Single-Phase, Two-Phase and Three-Phase Fields.

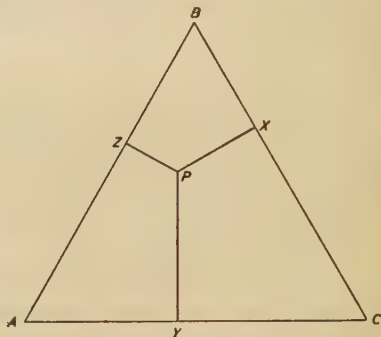


FIG. 10B.—Proportions of Components in a Ternary System.

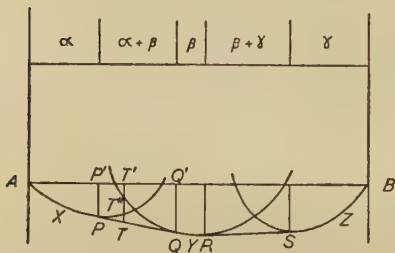


FIG. 10C.—Free Energy Curves for a Binary System.



FIG. 10D.—Free Energy Curves for a Ternary System.

The diagrams shown here represent sections at about  $500\text{--}600^\circ\text{C}$ . below which the alloys undergo practically no change at the rates of cooling employed.

An inspection of the ternary diagrams shows that each contains several areas of single phase indicated by Greek letters  $\alpha$ ,  $\beta$ ,  $\gamma$ ,  $\delta$ , &c. Some of these areas extend from the edge of the triangle inwards; in other words, phases found in the binary alloy persist when there is admixture of the third component. In other cases the area of single phase does not reach any boundary; such phases are only formed as alloys of all three components. The areas of single phase, except where they reach the edges of the triangle, are bounded by curved

lines. Two-phase areas are bounded by two curved lines, the boundaries of either phase, and two straight lines, the limiting tie-lines. The apices of the three-phase triangles touch areas of single phase at points of inflection on their boundaries.

The geometry of such a diagram is more readily grasped if it is regarded as a result of the law that the system when in equilibrium has a minimum value of total free energy. The geometrical construction for a two-component system of metals *A* and *B* at a given temperature *T* is shown in Fig. 10c, atomic composition being plotted horizontally. Ordinates represent free energy for a standard amount, such as a given total number of atoms, of each composition. We are only concerned with differences in free energy, so the line *AB* is taken to be the standard from which free energy is measured and represents the free energy of the corresponding amounts of the components *A* and *B* in the pure state. The curve *X* represents the free energy of a solution of *B* in *A*. Starting from *A*, this curve dips below *AB*, hence small quantities of *B* go into solution in *A* because the free energy of the solution is less than that of the unmixed components. On the right-hand side, as shown by the curve *Z*, *A* is dissolved by *B*. The curve *Y* represents the free energy of an intermediate  $\beta$  phase, with a different structure from  $\alpha$  or  $\gamma$ . From the form of the curve it is clear that this structure has the lowest free energy over a certain range of intermediate compositions.

Suppose that, starting from *A*, we follow the free energy of compositions with increasing amounts of *B*. At first the lowest free energy is represented by points on the curve *X*, and the alloy forms a single phase  $\alpha$ . Beyond the point *P*, however, when the common tangent *PQ* touches the curve *X*, the alloy breaks up into two phases. At the composition represented by the line *TT'*, for instance, the  $\alpha$  phase would have free energy *T'T''*. On the other hand, if the composition *T* breaks up into two phases of compositions *P* and *Q*, the free energy is *TT'*,\* which is lower than *T'T''*. This holds for a line joining any pair of points *PQ*, and since the lowest line is the tangent to the two curves, its points of contact mark the limits of the two-phase area. From *Q* to *R* there is a single phase  $\beta$ , from *R* to *S* two phases  $\beta$  and  $\gamma$  and from *S* to *B* a single phase  $\gamma$ . These phase areas are shown in the upper part of the figure. The phase areas can therefore be marked out by imagining a line rolling over the curves of free energy. Whenever a free-energy curve is low enough to stand "proud" of its neighbours, the line will rest on it over a certain range, and this is the range for which that particular phase extends. An infinite number of curves for other possible phases might be drawn, but these phases do not actually appear, because their curves are not prominent enough to be touched by the rolling line. The relative position of the curves varies with temperature. Phases will appear or disappear, and their ranges alter,

\* This follows because  $TT' = \frac{T'Q'}{P'Q'} \cdot PP' + \frac{P'T'}{P'Q'} \cdot QQ'$ .

in accordance with the relative prominence of the corresponding curves of free energy.

The corresponding geometrical construction for three components is shown in Fig. 10D. Atomic composition is represented by points in the triangle as above. The curves of free energy now become surfaces, which are shown above the zero plane instead of below, to facilitate drawing the diagram. The rolling line of Fig. 10C becomes a plane. When this rolls over a single curve, the point of contact represents a composition of single phase. When it rolls over two curves, the lowest free energy is attained by breaking up into two phases the compositions of which are the two points of contact joined by a tie-line. When it rests on three curves, the points of contact are the apices of a triangle which is a three-phase area. If the complex ternary equilibrium diagrams are looked at from this point of view their form becomes clear. One may picture a series of rounded bosses erected on the triangular base, each being a surface representing the variation of free energy with composition for a given phase. A plane rolls over these bosses. The rounded boundaries of the single-phase areas follow the points where the plane touches while rolling over two surfaces. At the apex of a three-phase triangle the boundary abruptly changes direction because the plane, after momentarily touching three bosses, begins to roll over another pair. A phase extending over a large area must have a gently rounded free-energy surface over which the plane rolls while touching that surface alone. The phases of small area are sharply rounded bosses, so that the point of contact is reduced to a limited range. In other words, the free energy rapidly increases on departing to any great extent from a certain optimum composition; an extreme case would be the precise composition of a "chemical compound," any departure from which involves a large increase in energy, so that the boss becomes a sharp peak on which the plane pivots.

It has not hitherto been possible to calculate the surfaces of free energy from first principles; their general contour can only be inferred from the shape of the phase boundaries found by experiment. There is one feature, however, which may well be emphasised. Although the phase boundaries appear to be so complex in form, and show such rapid changes in outline with change of temperature, the form of the free-energy surfaces and the law of their change with temperature may be quite simple. The boundaries of the phase areas are very sensitive to slight changes in contour and relative height of the surfaces; they are like the rapid and complex changes in contour of sandbanks laid bare by a slowly receding tide. Since the precise outlines of the phase areas correspond to a sensitive secondary effect of this kind, it is not worth while laying too much stress on their exact delineation in a first survey of the composition field, or taking extreme pains to attain equilibrium. For a study of metal-chemistry, the main point is the listing and examination

of the phases the free energy of which is sufficiently low to result in their appearance in appropriate conditions. To return to the analogy of the sandbanks, the main point is not to determine their exact outline at all states of the tide, but to know that shoals exist in those areas.

*Ternary Equilibrium Diagrams which have been Established in the Present Investigation.*

The six diagrams so far established are shown in Figs. 12, 13, 14, 15, 16 and 17. It is ultimately intended to examine the diagrams for all triads of the metals chromium, iron, cobalt, nickel, copper and aluminium, twenty in all.

The exploration of the whole ternary field does not require the examination of as many compositions as would at first sight seem necessary. This is so because the powder photographs, in addition to identifying the one, two or three phases present, also indicate the relative amounts of these phases and their approximate composition. Phases are identified by the pattern of lines characteristic of each, and the relative amounts estimated by the relative strengths of these patterns. Composition can be estimated as follows: Suppose a composition is made up as represented in Fig. 10A by the point  $C_1$ , which is just outside the single-phase area. It will be for the most part the  $\beta$  phase, with a small amount of  $\alpha$ . Even a rough estimate of the proportion of  $\alpha$  is sufficient to fix with considerable accuracy the position of the phase boundary in the neighbourhood of  $C_1$ . We may suppose the general directions of the tie-lines to be known, and the short distance of the  $\beta$  boundary from  $C_1$  along the tie-line may be deduced from the proportions of  $\alpha$  to  $\beta$ . The lattice constant or scale of the structure generally varies with composition, and a few points, such as  $C_1$ , establish the relation between lattice constant and composition along the boundary. If an alloy is now made up with composition  $C_2$ , it will be mostly  $\alpha$  with a small admixture of  $\beta$ . The amount of  $\beta$  fixes the phase boundary in the neighbourhood of  $C_2$ . The lattice constant of the  $\beta$  constituent indicates its composition, and thus gives the direction of the line  $XY$  running through  $C_2$  to the  $\beta$  boundary; as explained above, any composition  $Q$  along the line splits up into the two phases at its ends. Hence a few points, such as  $C_1$  and  $C_2$ , near the boundaries both fix the boundaries and show how the tie-lines run. Similarly, a powder photograph of a single composition inside the three-phase triangle determines its apices, because the lattice spacings of the three phases indicate their compositions. The apices can be more exactly fixed by making up three-phase alloys close to the corners of the triangle. This may serve to show how a relatively small number of judiciously chosen compositions serves to outline the phase areas. Given the binary systems along the edges of the composition triangle, the number of ternary alloys to be made up is in actual practice not much larger than that required to establish each binary.



As an example, the compositions examined in determining the iron-nickel-aluminium diagram are shown as circles in Fig. 12.

Some features of the individual ternary equilibrium diagrams are described below, but these may be prefaced by a few general remarks. The element aluminium is contrasted in its properties to the other five, chromium, iron, cobalt, nickel and copper. Ternaries of the latter are relatively simple, consisting for the most part of large  $\alpha$  face-centred cubic and  $\beta$  body-centred cubic areas, separated by two-phase and three-phase areas. It is interesting that three-phase areas can exist when only two types of structure,  $\alpha$  and  $\beta$ , are present. The iron-copper-nickel diagram affords an example, having a three-phase triangle with a  $\beta$  phase at one corner and two  $\alpha$  phases of different compositions at the others. The plane in the free-energy construction rests upon the  $\beta$  surface and two points of the  $\alpha$  surface separated by a shallow depression or valley in the area shown as  $\alpha + \alpha'$ . As the plane rolls over the  $\alpha$  surface the flanks of the valley close in until the plane touches at a single point.

The features of the iron-nickel-aluminium, iron-copper-aluminium and nickel-copper-aluminium ternaries are very different from the above. The  $\alpha$  face-centred and  $\beta$  body-centred phase areas are confined to the part of the diagram where the proportion of aluminium is less than about 50%. The  $\alpha$  phase has the smallest proportion of aluminium, and is succeeded by the  $\beta$  phase. When the aluminium content is increased still further, complex phases appear which are modified forms of the  $\beta$  structure. The  $\gamma$  structure has already been described in the chromium-aluminium system. The  $\delta$  structure, which includes  $\text{Ni}_2\text{Al}_3$ , is derived from the body-centred structure by taking a system of aluminium atoms at cube corners and nickel atoms at cube centres and removing one-third of the nickel atoms. Copper and aluminium form no  $\beta$  structure, but pass directly from  $\alpha$  to  $\gamma$ .

These modified  $\beta$  structures have a small phase range compared with  $\alpha$  and  $\beta$ . They are followed by still more complex structures of still smaller range, many of which have not yet been analysed. Then in each diagram there is a final region (when the proportion of aluminium exceeds about 70%) where no single-phase areas exist. Aluminium dissolves such small quantities of the other elements that the phase area which includes the aluminium corner is too small to show in the diagram. The tie-lines therefore all run out radially from the aluminium corner to the various complex phases in the vicinity.

Certain ternary equilibrium diagrams are reproduced on a reduced scale in Fig. 11, together with triangles in which contours are drawn for equal ratios of electrons to atoms. The Hume-Rothery rule states that similar structures are formed when the ratio of free electrons to atoms stands at certain characteristic values. In this case the position of iron and nickel is somewhat anomalous. They



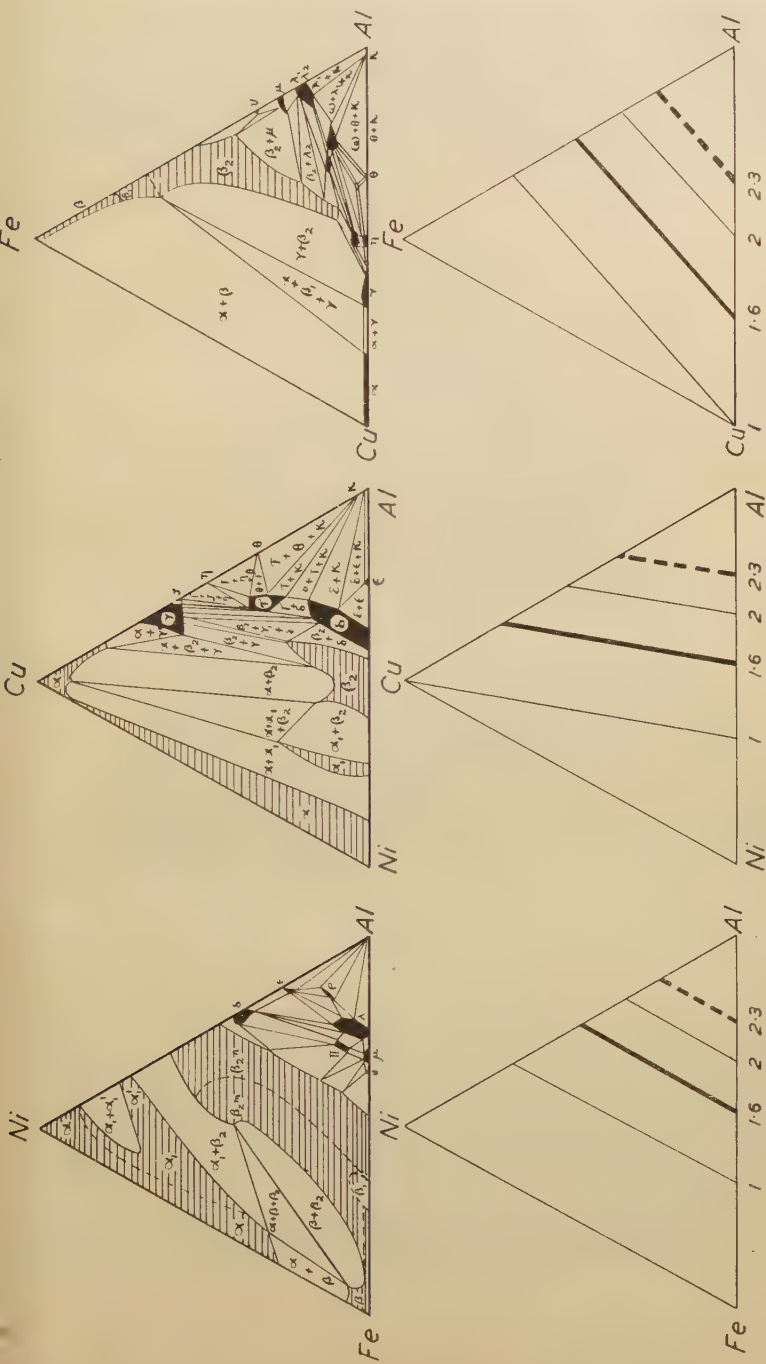


Fig. 11.—A Comparison of the Ternary Diagrams for FeNiAl, CuNiAl and FeCuNi, with the corresponding electronic ratios.

are reckoned as having no free electrons, copper as having one, and aluminium three, so that the contours for one and two free electrons per atom run as shown by the light lines in the figure. Although there are many irregularities, there is a suggestive rough parallelism between the run of the phase boundaries and tie-lines on the one hand, and the free-electron contours on the other. As a broad

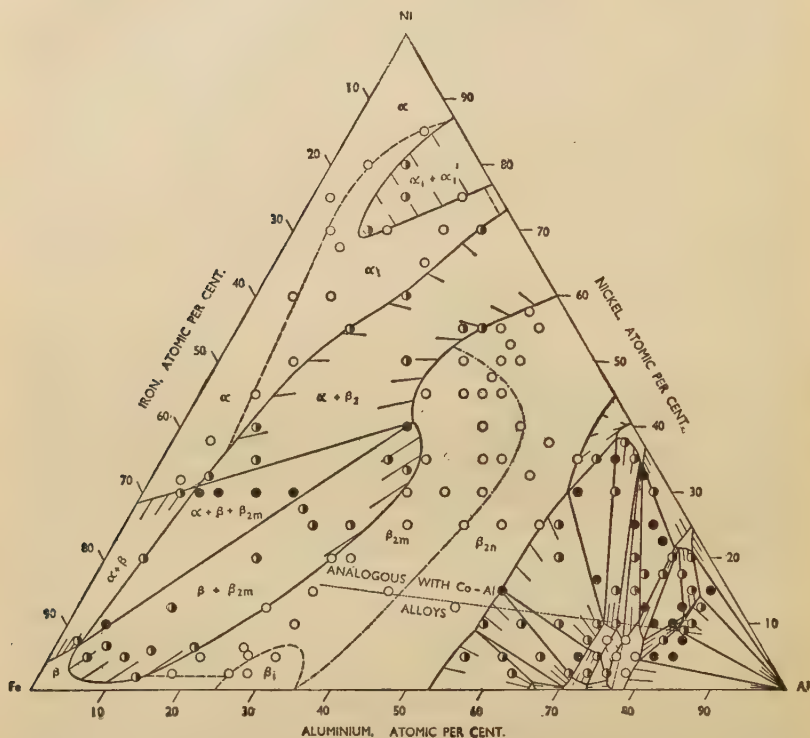


FIG. 12A (see FIG. 12B).—The Iron-Nickel-Aluminium System, general (*Journal of the Institute of Metals*, 1940, vol. 66, p. 58).

generalisation, it may be said that the  $\alpha$  and  $\beta$  structures are confined to the left of the 1.6 contour (full line) and the complex structures lie between this and the 2.3 contour (dotted line). The Hume-Rothery rule applies to ternary alloys as to binaries, but in an erratic and imperfect way, which shows that, although there is an obvious correlation, the electron-atom ratio is only one of several factors determining which phases appear.

The following points in the ternary diagrams are of interest.  
*Iron-Nickel-Aluminium.*<sup>(18, 19)</sup>—The whole ternary area is shown

in Fig. 12A, and an enlargement of the aluminium-rich corner in Fig. 12B.

The extensive  $\alpha$  area is shown divided by a dotted line into the regions  $\alpha$  and  $\alpha_1$ , the latter having a superlattice structure. Along the Ni-Al edge there is a two-phase region which separates alloys which are both face-centred cubic, but with slightly different



FIG. 12B (see FIG. 12A).—The Iron-Nickel-Aluminium System; enlargement of aluminium-rich corner (*Journal of the Institute of Metals*, 1940, vol. 66, p. 59).

spacings. This two-phase region narrows and finally vanishes as iron is added. As mentioned above, it has been shown by Sykes<sup>(13)</sup> that the alloy  $\text{Ni}_3\text{Fe}$  after undergoing suitable heat treatment has a superlattice structure similar to that of  $\alpha_1'$ , with iron atoms at the cube corners. It will be realised that the position of the boundary between superlattice and no superlattice depends on the thermal treatment.

The body-centred cubic  $\beta$  area, also very extensive, exhibits complex superlattice variations.  $\beta$  is simple body-centred, like

iron, with a random replacement of iron by aluminium atoms.  $\beta_1$  has a superlattice like that of  $\text{Fe}_3\text{Al}$ , where aluminium is at half the cube centres, the remainder, together with the corners, being occupied by iron.  $\beta_2$ , which extends across the triangle including  $\text{FeAl}$  to  $\text{NiAl}$ , has aluminium atoms at cube centres, and

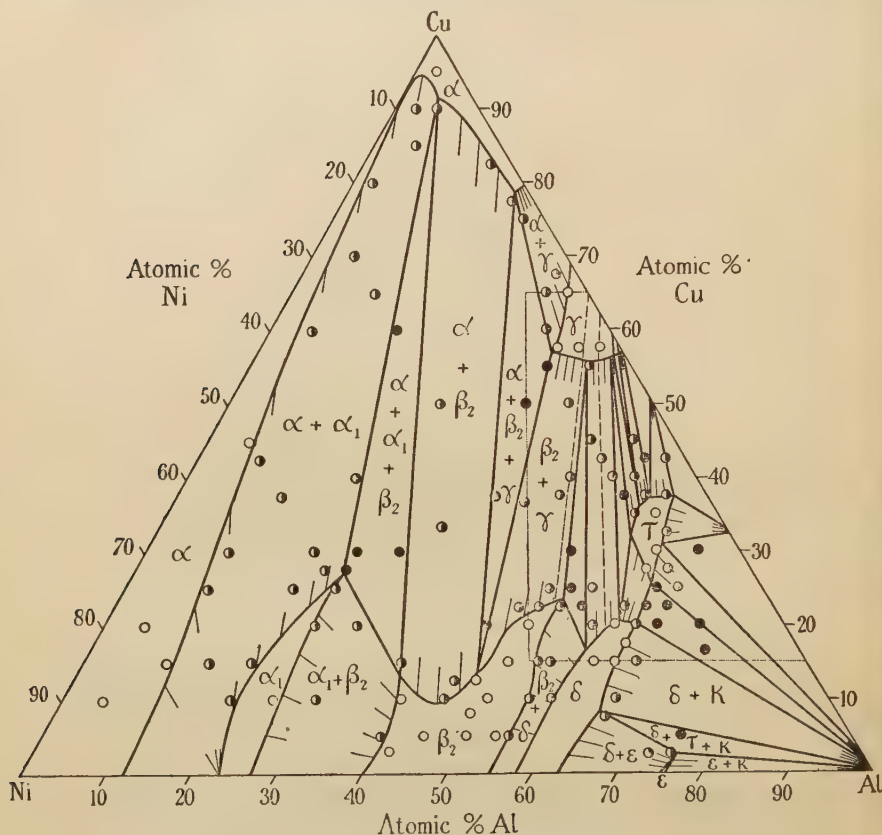


FIG. 13A (see FIG. 13B).—The Copper-Nickel-Aluminium System, general (*Proceedings of the Royal Society*, 1938, vol. 167, p. 423).

iron or nickel atoms at cube corners. The dotted boundary divides the area  $\beta_{2m}$ , which is ferromagnetic at room temperature, from the area  $\beta_{2n}$ , which is not ferromagnetic.

The complex alloys richer in aluminium are listed below. A point of special interest is that some ternary alloys in the iron-nickel-aluminium system have the same types of structure as the binary cobalt-aluminium alloys.<sup>(19)</sup> In fact, a line shown in the

figure drawn through the ternary diagram from near the aluminium corner towards a point which represents the composition  $\text{Fe}_2\text{Ni}$  passes through a succession of phases which is very similar to that in the cobalt-aluminium diagram. For instance,  $\text{Fe}_3\text{NiAl}_{10}$  ( $\pi$ ) is isomorphous with  $\text{Co}_2\text{Al}_5$ , and  $\text{FeNiAl}_9$  ( $\rho$ ) is isomorphous with  $\text{Co}_2\text{Al}_9$ .

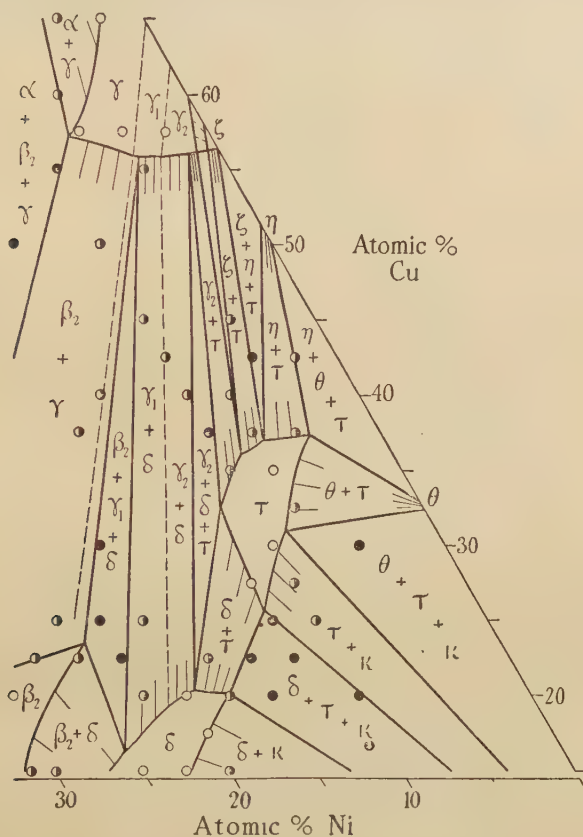


FIG. 13B (see FIG. 13A).—The Copper-Nickel-Aluminium System; enlargement of portion (*Proceedings of the Royal Society*, 1938, vol. 167, p. 424).

The similarity of the powder photographs given by the latter pair of alloys may be seen in Fig. 21. Four phases are analogous in the two systems, and occur in the same order,  $\alpha$ ,  $\beta_2$ ,  $\pi$  and  $\rho$ .

*Copper-Nickel-Aluminium.*<sup>(20)</sup>—The ternary diagram is shown in Fig. 13A, and an enlargement of the most complex portion in Fig. 13B. In this diagram the  $\alpha$  area (face-centred cubic with no superlattice) and  $\alpha_1$  area (face-centred cubic with a superlattice) are quite separate.



The gap between  $\alpha$  and  $\alpha_1$  found in the nickel-aluminium alloys does not close when copper is added. The alloy  $\alpha_1$  approximates to  $\text{Ni}_3\text{Al}$  in which nickel can be replaced to a large extent by copper. The replacement of nickel by copper is also to be observed in the  $\delta$  phase, which extends as a long promontory into the ternary area.

The  $\beta$  body-centred phase field exhibits an interesting feature which has already been commented on in describing the nickel-

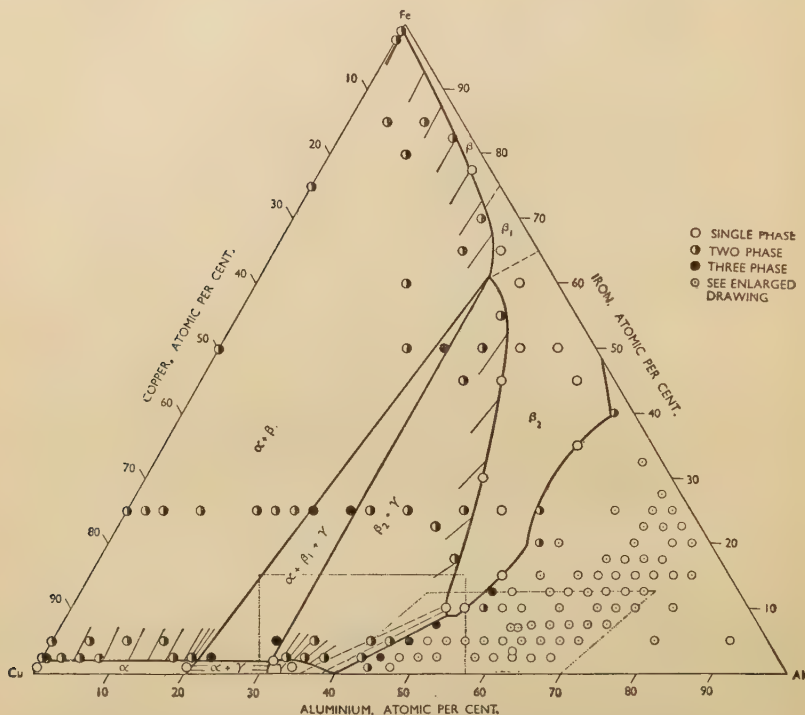


FIG. 14A (see FIG. 14B).—The Iron-Copper-Aluminium System, general  
(*Journal of the Institute of Metals*, 1939, vol. 65, p. 391).

aluminium system. The aluminium-poor side of the field is quite normal. The unit cube contains two atoms, and has a simple superlattice structure with the aluminium atoms occupying cube centres as far as possible, the residue being made up with nickel and copper atoms. The cube corners are completely filled by nickel and copper atoms. On the aluminium-rich side the average number of atoms per cell falls below two, the lowest value being 1.85. The same phenomenon is observed in the iron-nickel-aluminium  $\beta$ -phase field. In this latter case all alloys with less than 50% of aluminium

contain two atoms per unit cell, whereas with increase of aluminium beyond this amount the average number of atoms falls steadily to 1.8. Lipson <sup>(21)</sup> has recently pointed out that the boundary line beyond which the number falls below two corresponds in each case to an electron-atom ratio of 1.5. It will be remembered that the numbers of electrons assigned to iron, nickel, copper and aluminium are 0, 0, 1, 3, respectively. In the iron-nickel-aluminium

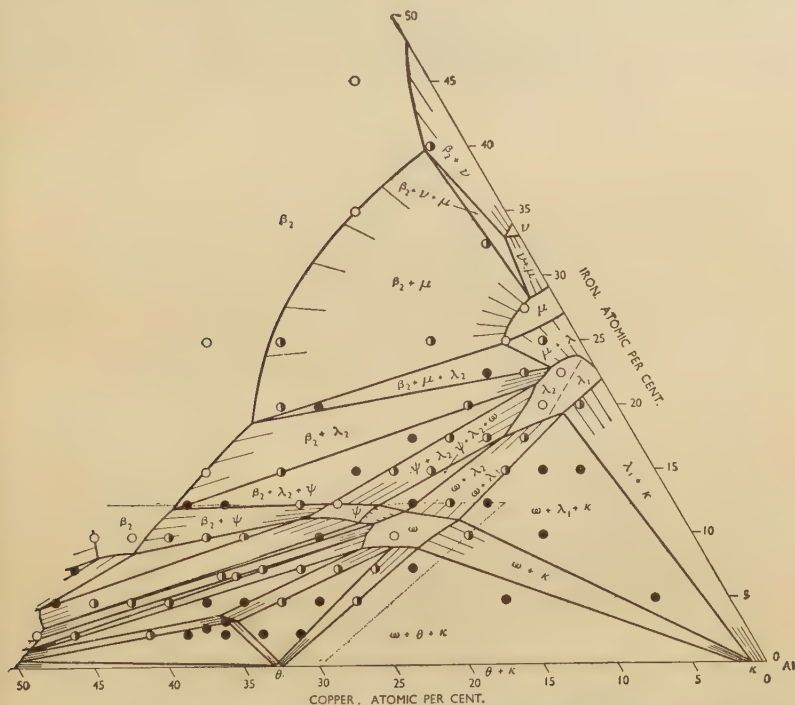


FIG. 14B (see FIG. 14A).—The Iron-Copper-Aluminium System; enlargement of aluminium-rich portion (*Journal of the Institute of Metals*, 1939, vol. 65, p. 405).

system the boundary for which there are 1.5 electrons per atom or three electrons per unit cell is the same as that for one aluminium atom per unit cell, so in this case an alternative explanation of the "defect" lattices beyond this boundary is that the structure cannot tolerate more than one aluminium atom per unit cell. In the copper-nickel-aluminium system, however, copper has one electron per atom, and the boundary for 1.5 electrons per atom or three electrons per unit cell does not coincide with that for one aluminium atom per unit cell as copper is added. The observed

boundary when the number of atoms begins to fall turns out to be that for the 1.5 electron-to-atom ratio. It is to be observed, however, that although atoms drop out, the electron-atom ratio continues to rise to a maximum value of about 1.7.

*Iron-Copper-Aluminium.*<sup>(22)</sup>—The  $\alpha$ - and  $\beta$ -phase fields are shown in Fig. 14A, and the aluminium-rich end of the diagram in Fig. 14B. Iron and copper are almost insoluble in each other. The addition of aluminium to copper does not increase its solubility for iron, and the  $\alpha$ -phase field is very restricted. On the other hand, the addition of aluminium to iron rapidly increases the extent to which copper is dissolved, and the  $\beta$ -phase field extends almost across the diagram.

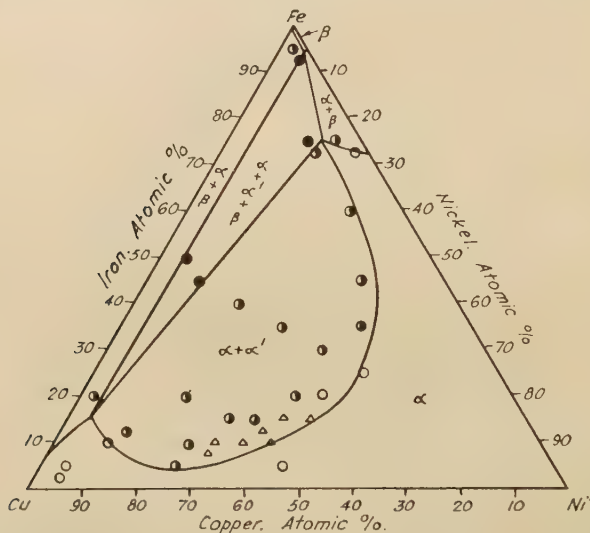


FIG. 15.—The Iron-Copper-Nickel System.

It will be remembered that there is no  $\beta$  phase in the copper-aluminium system at room temperature, but as it exists at higher temperatures, the  $\beta$  phase probably then extends right across. The phase has a superlattice of the usual type, with aluminium atoms at cube centres and iron or copper atoms at cube corners. The phenomenon of defect lattices on the aluminium-rich side of the  $\beta$ -phase field is found here as in copper-nickel-aluminium and iron-nickel-aluminium.

*Iron-Copper-Nickel* (see Fig. 15).—The  $\alpha$  phase is very extensive, and there is a large  $\alpha + \alpha'$  region where two face-centred structures coexist. The  $\beta$  phase is restricted to a minute area around the iron corner. It is interesting to see how rapidly the amount of dissolved iron increases when nickel is added to copper. At higher temperatures

the bay in the  $\alpha$  region rapidly closes in, increasing still further the region covered by  $\alpha$ .

*Iron-Nickel-Chromium* (see *Fig. 16*).—The main phases are  $\gamma$  (face-centred nickel),  $\alpha$  (body-centred iron) and  $\alpha'$  (body-centred chromium). The last two are separated by the curious  $\rho$  alloy of iron and chromium. At higher temperatures  $\alpha$  and  $\alpha'$  join up and become a continuous region, and the diagram becomes a very simple one with only the  $\gamma$  nickel structure, and the  $\alpha$  structure including iron and chromium.  $\rho$ , which has so limited a range in the iron-chromium diagram, extends considerably when nickel is added.

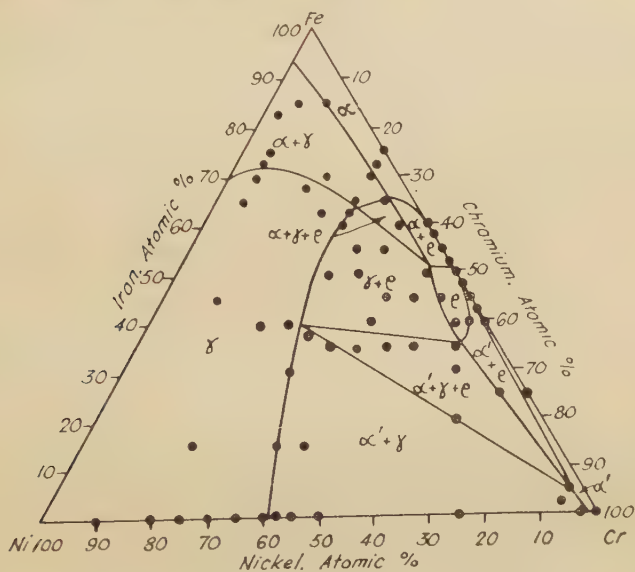


FIG. 16.—The Iron-Nickel-Chromium System.

*Iron-Nickel-Cobalt* (see *Fig. 17*).—This consists for the most part of  $\alpha$  and  $\gamma$  regions. The hexagonal structure of cobalt ( $\epsilon$  in the diagram) introduces a slight complication at the corner.

The following is a list of phases found in the above alloys :

(a) Simple structures.

- $\alpha$  Face-centred cubic.
- $\alpha_1$  Face-centred cubic with a superlattice of the  $\text{Ni}_3\text{Al}$  type.
- $\beta$  Body-centred cubic.
- $\beta_1$  Body-centred cubic with a superlattice of the  $\text{Fe}_3\text{Al}$  type.

$\beta_2$  Body-centred cubic with a superlattice of the FeAl and NiAl types.

(b) Structures which may be regarded as variants of the body-centred structure, but with certain atoms removed and a consequent degradation in symmetry.

$\gamma$   $\text{Cu}_9\text{Al}_4$ . Complex cubic structure with 52 atoms per unit cell, the  $\gamma$  type.  $\gamma_1$  ( $\text{Cu}_{32}\text{Al}_{19}$ ) and  $\gamma_2$  ( $\text{Cu}_3\text{Al}_2$ ) are forms of  $\gamma$  with lower symmetry, and a reduction from 52 to 51 or 49 atoms.

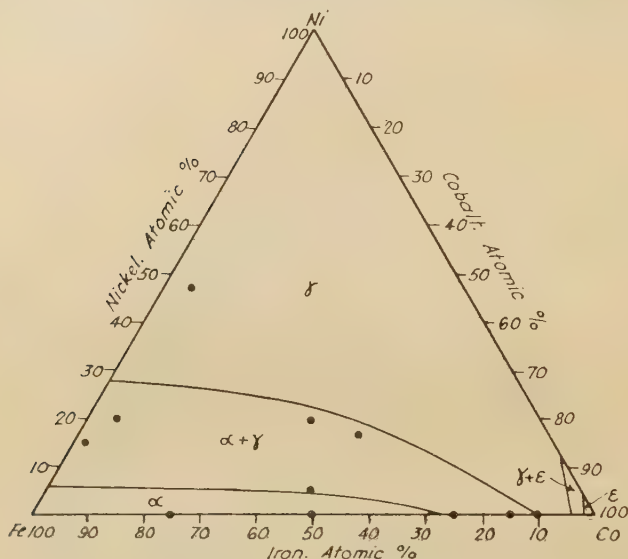


FIG. 17.—The Iron-Nickel-Cobalt System.

$\delta$   $\text{Ni}_2\text{Al}_3$  A trigonal (pseudo-cubic) structure with 20 atoms per unit cell.

$\epsilon$   $\text{NiAl}_3$ . Orthorhombic structure with 16 atoms per unit cell.

$\zeta$   $\text{Cu}_4\text{Al}_3$   
 $\eta$   $\text{CuAl}$  } Structures related to  $\text{Ni}_2\text{Al}_3$  but with large units and lower symmetry.

$\phi$   $\text{FeCu}_{10}\text{Al}_{10}$   
 $\tau$   $\text{Cu}_3\text{NiAl}_6$ . A complex cubic or pseudo-cubic structure.

(c) Highly complex structures, the majority of which have not as yet been analysed.

$\lambda$   $\text{FeAl}_3$ . Only stable above  $550^\circ\text{C}$ .

$\mu$   $\text{Fe}_2\text{Al}_5$ .



- v  $\text{FeAl}_2$ .
- $\lambda_1$   $\text{Fe}_2\text{Al}_7$ . Stable below  $550^\circ$ . Extends into Fe-Cu-Al and Fe-Ni-Al ternary systems.
- $\lambda_2$   $\text{Fe}_4\text{NiAl}_{15}$ ,  $\text{Fe}_4\text{CuAl}_{15}$ . These are modifications of the  $\lambda$  type and are only found as ternary alloys.
- $\pi$   $\text{Fe}_3\text{NiAl}_{10}$ . Isomorphous with  $\text{Co}_2\text{Al}_5$ . Contains 28 atoms in a hexagonal unit cell.
- $\rho$   $\text{FeNiAl}_9$ . Isomorphous with  $\text{Co}_2\text{Al}_9$ .
- $\psi$   $\text{FeCu}_{10}\text{Al}_{18}$ ? Composition rather uncertain.
- $\chi$   $\text{FeCu}_2\text{Al}_6$ .
- $\omega$   $\text{FeCu}_2\text{Al}_7$  Tetragonal.

It will be realised that in the complex cases the numbers used to express the proportions of atoms are only approximate, and that the nearest integers are used for convenience, and have no other significance. It may be emphasised again that although the many complex alloys are very interesting from a purely scientific point of view, as casting light on metal-chemistry, they are too brittle to be of practical importance. The alloys used technically are  $\alpha$  or  $\beta$  phases, or a combination of these.

#### (5) Structures of Submicroscopic Order of Magnitude.

An indication has been given in the introduction of the nature of these structures and of the manner of their analysis by X-rays. The following rough classification in ascending scales of magnitude may be made :

- (a)  $10^{-8}$  cm. This is the order of magnitude of the atomic pattern in the crystalline structure of the phases. For instance, the interatomic distances in all alloys considered in this paper lie between  $2.5 \times 10^{-8}$  cm. and  $2.9 \times 10^{-8}$  cm. The repeat of the units of pattern (axes of unit cell) is in general between  $2 \times 10^{-8}$  cm. and  $12 \times 10^{-8}$  cm.
  - (b)  $10^{-7}$  cm. The segregation which leads to one type of age-hardening appears to take place in a pattern on this scale.
  - (c)  $10^{-6}$  cm.
  - (d)  $10^{-5}$  cm.
- { Incipient precipitation leading to age-hardening, resistance to deformation, coercive force in magnets, &c., is on this scale.

“ Martensitic ” structures, due to changes of phase unaccompanied by atomic diffusion, have a structure on the  $10^{-6}$  cm. scale.
- (e)  $10^{-4}$  cm. and larger. Structures of this magnitude become visible under the microscope in polished and etched specimens.

Examples are accumulating of the possibility of exploring classes (b), (c) and (d) by X-ray methods, not only in alloys, but in other complex structures such as those of certain minerals. If a periodic variation is superimposed on the lattice structure of the crystal, the interval of its repeat being on a larger scale than that of the crystal pattern, the effect is to turn the simple spots or lines of the pattern diffracted by the perfect lattice into complex groups of spots or lines. A very similar effect is well known in the case of optical gratings. If a grating is ruled by a machine which has some defect, such as a periodic error in its screw, the lines will be periodically displaced from their ideal position, or, to put it in another way, they will alternately be spaced slightly closer in one region and slightly farther apart in another. Each spectral line is then accompanied by "ghosts." What should be a simple line with sharp definition becomes a group of lines, often a central line with fainter companions on either side. The effect is a potential source of error in the analysis of the fine structure of spectral lines, and special precautions are taken to avoid it. The phenomenon is also familiar in wireless transmission. Speech is carried by fluctuations in the intensity or frequency of the carrier wave, and these are represented in the side-band of frequencies which replaces the single frequency of the simple carrier wave; the "ghosts" are analogous to the side-band.

The following example illustrates the type of periodicity which may occur in an alloy structure. An alloy approximating in composition to  $\text{FeCu}_4\text{Ni}_3$  is face-centred cubic at high temperatures (above  $800^\circ\text{C}.$ ), and may be preserved in the state of a single phase by a rapid quench. In this state no ordered arrangement of the atoms can be detected. When annealed for a week at  $650^\circ\text{C}.$  it breaks up into two phases the compositions of which are *A* and *B*, where *A* is approximately  $\text{FeCu}_{13}\text{Ni}_6$  and *B* is about  $\text{FeCuNi}_2$ . Both these phases are also face-centred cubic, but they have appreciably different lattice parameters. The sides of the cubic unit cells are  $3.587\text{ \AA}.$  for *A* and  $3.565\text{ \AA}.$  for *B*. The quenched alloy gives a sharp X-ray powder pattern characteristic of a face-centred cubic lattice, as shown in Fig. 22 (a). The powder pattern of the annealed alloy shows all the lines doubled, corresponding to the two types of crystal with different parameters, as shown in Fig. 22 (b).

When the alloy cools at an intermediate rate ( $30^\circ\text{C}.$  per hr.), it gives a third type of pattern as shown in Fig. 22 (c). Some of the lines are doubled, some break up into triplets, and even higher numbers are indicated in lines with higher indices  $hkl$ .

This powder photograph may possibly be interpreted as follows : It is supposed that with the intermediate rate of cooling employed the separation into two phases does not pass to completion. Regions of two compositions *A* and *B* are produced in the crystal, but these regions are so small in extent that there is no disruption into separate crystallites, the crystalline pattern running through regions of both

types without any break in continuity. If the regions are sufficiently small this must be the case; the lattice spacings of the fully developed separate phases only vary by 0.7%, and hence contiguous crystals would get "out of step" only over distances corresponding to a hundred atoms. Smaller regions of the two compositions can be accommodated by a relatively slight strain. The actual structure which appears to be indicated by the photograph is one of sheets or lamellæ alternately rich in copper and iron, parallel to the three cube faces of the crystal. Each lamella is at least several hundred atoms wide, and about fifty atoms thick. Two sheets of different composition have a common face, and hence the axes of each pattern parallel to the face must be the same. These may be termed the "*a*" axes, and have a length of 3.576 Å. The axes at right angles to the interface are longer for the *A* composition ( $c_1 = 3.610$  Å.) and

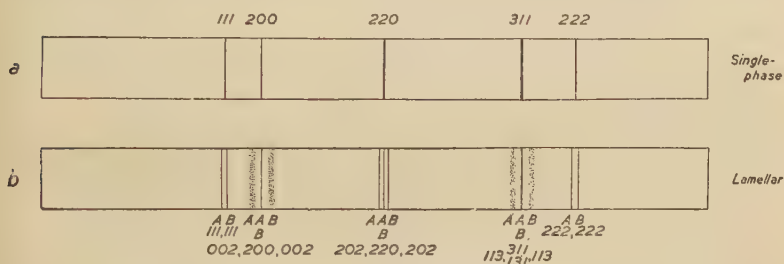


FIG. 18.—Diagrammatic Representation of Fig. 22 (a) and (c). (a) Single phase. (b) Lamellar. Note :—The separation between *A* and *B* which is proportional to  $\tan \theta$  is here given without allowing for the changes in angle. In the actual photograph the 222 lines are far more widely resolved than the 111 lines because  $\tan \theta$  is four times greater for 222 than for 111.

shorter for the *B* composition (3.543 Å.). Each region is thus tetragonal. This would appear to be due to an effort of the crystals to achieve the different atomic volumes of the separate phases, while retaining common *a* axes. Fig. 18 shows diagrammatically how such a structure would affect the powder pattern.

To take the line 200 as an example, the planes parallel to 100 and 010 run continuously through the lamellæ of either sort and have a single spacing of  $a/2$ . The planes 002 of region *A* have a spacing  $c_1/2$ , and those of region *B* of  $c_2/2$ , and these produce the two wing lines as shown. Further, the 200 and 020 spectra will be sharp because the corresponding planes repeat over long distances, whereas  $002_A$  and  $002_B$  are diffuse because they are due to small groups of planes parallel to the face of the lamellæ.\*

Other lines break up differently. 111, for example, breaks up

\* The above refers to a group of planes parallel to any one cube face. Whichever cube face the lamellæ are parallel to, their *c* axes are to be taken perpendicular to the lamellæ and their *a* axes in the plane of the lamellæ.

into  $111_A$  and  $111_B$ , each being moderately diffuse. 220 breaks up into a sharp central line due to  $220_A$  and  $220_B$ , one wing due to  $202_A$  and  $022_A$ , and another due to  $202_B$  and  $022_B$ . 311 breaks up into four lines. In the centre is a close doublet of rather sharp lines  $\{311_A 131_A\}$  and  $\{311_B 131_B\}$ . The doublet is flanked by the more diffuse lines  $113_A$  and  $113_B$ .

Fig. 19 shows a photometer curve of the complex lines 220, 311 and 222 and their analysis into their components. The resolution is not sufficient to distinguish the  $\alpha$  doublets or the inner doublet of 311.

A vast new field of enquiry is opened up by such examples as the above. It demands an X-ray technique of a very high order, and much attention has been devoted in recent years to developing cameras with higher resolution. Resolution depends upon the

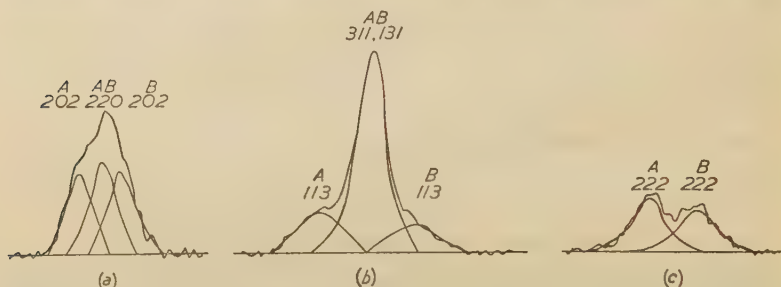


FIG. 19.—Photometer Curves from the X-ray Powder Photograph, Fig. 22 (c). (a) 220 complex. (b) 311 complex. (c) 222 complex.

design of the slit system for the incident beam, the dimensions and centring of the specimen, and the diameter of the camera. It is increased by shorter slits, a smaller specimen and a larger camera, but all three factors also increase the time of exposure, and a balance has to be struck. The examples shown in Fig. 22 were obtained with a camera 19 cm. in dia. and a time of exposure of 1 hr.

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## B.—THEORY OF THE ORDER-DISORDER TRANSFORMATION.

### (1) *Order.*

The very brief outline of the theory of the order-disorder change in alloys which is given here is merely intended to help towards an understanding of the practical work carried out by Sykes and his collaborators. Although the intensive study of this change is of recent growth, much work has been done. An excellent summary by Nix and Shockley,<sup>(23)</sup> published in the *Reviews of Modern Physics* by the American Physical Society, appeared in January, 1938. The bibliography lists 140 papers, most of them published since 1932, and many more have appeared since the list was drawn up. The transformation is amenable to mathematical treatment, and presents a very fascinating problem in statistical mechanics; hence it has attracted the attention of many able mathematical physicists.

The nature of the order-disorder change has already been described in the introduction, and an example has been given in Fig. 3 of the recognition of the ordered state by the appearance of new "superlattice" lines in the powder photograph of the alloy. The example given there is of a body-centred cubic structure of composition  $AB$ , with random arrangement of the  $A$  and  $B$  atoms on the lattice points at high temperatures, and an ordered arrangement of one atom at cube centres and the other at cube corners at low temperatures. A characteristic feature is the



equivalence of the two positions as far as the lattice is concerned. The distinction between corners and centres only arises when by chance the one is selected as the favoured position for the  $A$  atoms and the other for the  $B$  atoms, or *vice versa*, in the initiation of the ordering process. Another characteristic feature is that like atoms tend to get as far apart as possible in the structure. When it is perfectly ordered,  $A$  atoms are entirely surrounded by  $B$  atoms as nearest neighbours and *vice versa*. An opposite tendency for like atoms to get together would, if continued far enough, result in a separation of two phases.

The first X-ray evidence of the change was given by Johansson and Linde.<sup>(24)</sup> Early theoretical treatments were given by Gorsky,<sup>(25)</sup> Borelius, Johansson and Linde,<sup>(26)</sup> Wagner and Schottky,<sup>(27)</sup> Dehlinger and Graf,<sup>(28)</sup> Bragg and Williams.<sup>(29)</sup> Many authors, notably Bethe,<sup>(30)</sup> Peierls,<sup>(31)</sup> and Kirkwood,<sup>(32)</sup> have refined the theory.

All instances of the order-disorder transformation so far discovered occur in alloys which approximate in composition to the simple ratios  $AB$  or  $AB_3$ .

The order-disorder transformation is a "co-operational phenomenon." The ordered structure exists at low temperatures because it has a lower internal energy than the disordered structure. Starting with a state in which all the cube centres are occupied by  $A$  atoms ( $\alpha$  sites) and the corners by  $B$  atoms ( $\beta$  sites), work has to be done if an  $A$  and  $B$  atom are interchanged so that each becomes wrongly situated with respect to its neighbours. The disruptive influence of the heat movements tends to destroy the order by throwing an increasing number of atoms into the wrong places, or states of higher energy, as the temperature is increased. The peculiar feature of a co-operational phenomenon is that the tendency of each atom to remain in a certain state, in this case an ordered position, is due to the fact that its neighbours are in that state. Hence as the temperature is raised, not only does the disruptive effect of the heat movements increase, but also the energy difference between an  $\alpha$  and  $\beta$  site decreases because each atom has a decreasing number of ordered neighbours. Hence the disorganisation of the structure proceeds with ever-increasing rapidity, till at a certain critical temperature the regular superlattice disappears completely. A similar behaviour is shown in the case of ferromagnetism. A ferromagnetic metal like iron or cobalt loses this property when its temperature is raised above the "Curie point." Below this temperature the elementary magnets align themselves in more or less parallel orientations, each magnet tending to point in a direction in accord with those assumed by the majority of its neighbours. The disruptive effects of heat throw the magnets out of alignment, and as the temperature is increased the degree of intrinsic magnetisation due to parallel alignment decreases, and vanishes at the critical temperature or Curie point. Another case

is observed in the movements of certain radicals such as  $\text{CO}_3$  and  $\text{NO}_3$  in inorganic salts. At low temperatures these radicals have a certain freedom of movement, but their mean positions are fixed in accord with the crystalline temperature. As the temperature is increased, an increasing number are set in complete rotation about their centres, as opposed to vibration about a mean position. The bonds holding a radical from rotating are loosened as more of its neighbours rotate, hence a critical temperature is reached at which the last trace of order disappears and all the radicals rotate.

It will be seen that the phenomenon may be described as a simplified version of the melting of a crystal to form a liquid, the critical temperature being compared to a secondary melting point. When the alloy first crystallises from the melt, the atoms are arranged at random on the lattice points. At another temperature below the melting point a kind of second crystallisation sets in and the atoms take up ordered positions. The process is simpler than melting and solidification because the atoms in a liquid are very irregularly arranged, whereas in the present case they merely move from one lattice point to another. It is also different because the order may be only partial when it first sets in. We may distinguish two cases, starting with the alloy at low temperatures in the ordered state and raising the temperature. In the first, which is a rather special case, order may decrease continuously and finally disappear at the critical temperature, so that all intermediate states exist between complete order and complete randomness of arrangement. In the second, and more general, case order decreases but has not completely disappeared by the time the critical temperature is reached, and there is a sudden jump at this temperature from partial order to complete disorder. In both cases there is a varying degree of order below the critical temperature. In the case of melting and solidification the whole change from a crystal to a disordered liquid takes place at the melting point, but in the present case the process is spread over a range of hundreds of degrees, the critical temperature merely marking its sudden beginning.

## (2) *Physical Effects of the Order-Disorder Transformation.*

It requires energy to interchange a pair of atoms from positions of order to positions of disorder. As the temperature is raised and more atoms take up disordered positions, heat has to be supplied over and above that required to increase the thermal vibrations. The specific heat is therefore abnormally high. Sykes has made measurements of specific heat for alloys which undergo this transformation. The abnormal increase can be estimated with fair accuracy, because the normal specific heat of alloys when there is no transformation is given to a good approximation by the Dulong-Petit law, and may be deduced without serious error from the specific heats of the constituents. At low temperatures the degree

of order is high, and only changes slowly. As the temperature is raised disorder sets in more rapidly and the specific heat begins to rise. It rises to a very marked maximum just below the critical temperature, when it may have many times the normal value, and suddenly drops to nearly the normal value just above the critical temperature. The fall to what would be expected to be the normal value above the critical temperature is not complete, there being a slight abnormal increase due to what is called "local order," which will be explained below. In cases where the transition from order to disorder is continuous there is merely an increased specific heat. If there is a sudden jump at the critical temperature from partial order to complete disorder there is, in addition, a "latent heat" like that of fusion. The whole phenomenon of increased specific heat may in fact be compared to a latent heat which is spread over a temperature range instead of being wholly absorbed or emitted at the melting point.

Another striking effect of the order-disorder change is its influence on the electrical resistivity of the alloy. The ordered alloy has a resistivity proportional to the absolute temperature, like a pure metal. The disordered alloy has a much higher resistivity. In cases where the disordered state can be frozen in at room temperature by quenching, it is possible to examine the variation of resistivity with temperature. The alloy has a resistivity  $A + BT$ ,  $BT$  being a normal component proportional to the absolute temperature  $T$ , and  $A$  a constant resistivity due to the disorder. Interesting examples will be found in Sykes' work (Part II.), in particular the influence of the "domains" of ordered structure in the alloy  $\text{Cu}_3\text{Au}$ .

Dahl<sup>(33)</sup> has used electrical resistivity as a means of showing the destruction of order by plastic deformation in  $\text{Cu}_3\text{Au}$ . If this alloy in the ordered state is deformed by cold-drawing, its resistivity is greatly increased, and when the cross-section has been reduced to over half by the drawing, its resistivity becomes equal to that of the quenched disordered material.

The magnetic properties of an alloy also depend on the degree of order. A number of instances are given in the review by Nix and Shockley quoted above.

### (3) *Mathematical Treatment of the Order-Disorder Transformation.*

This may be very briefly referred to in order to outline the general principles. The most direct physical way is to consider the jumps of pairs of atoms, or perhaps larger groups, from the ordered to the disordered state and *vice versa*. In order that a pair may exchange places, enough thermal energy must momentarily accumulate at that point to lift the atoms over a certain "potential barrier." We may think of the ordered atoms as being on a certain energy level, the disordered atoms on a higher energy level, and a barrier or fence between the two over which

the atoms must be hoisted in order that the interchange may take place. A thermal blow which by chance attains an exceptionally high value imparts the necessary energy. The chance of getting a knock which sends a given atom from the high side to the low side is greater than one which does the reverse from low to high, because if the atom starts on the high level it has a lower barrier to surmount. Equilibrium is attained when the average number of atoms passing both ways is equal. Suppose we start at a given temperature  $T$  and with all the atoms on the low side. Thermal blows throw some over to the high side, *i.e.*, into disordered positions. At the same time some of those on the high side are knocked back, but at first the rate of transfer is unappreciable because the total number on the high side is so small. As time goes on, the average number on the high side increases till the number going back is equal to the number coming over to the high side, and the structure attains an equilibrium state of order characteristic of the temperature. It is a well-known law of thermodynamics that the height of the barrier does not influence the point of equilibrium, merely the rate at which it is attained. Put into a mathematical form, this condition gives the degree of order as a function of temperature.

Another way of expressing the condition for equilibrium, which is equivalent but more difficult to visualise, is to state that for equilibrium the free energy of the system must be a minimum. The free energy  $F$  is defined by :

$$F = U - T\phi,$$

where  $U$  is the internal energy of the system,  $T$  the temperature, and  $\phi$  the entropy. In the present case it is only necessary to consider the contributions to energy and entropy due to the relative distribution of the  $A$  and  $B$  atoms on the lattice, or the configurational energy and entropy. When  $T$  is small, variations in  $T\phi$  are unimportant and  $U$ , the internal energy, must be near a minimum; this is realised in the state of high order at low temperatures. The entropy  $\phi$  is a measure of the "probability" of a given state of affairs. A state of nearly perfect order is one of very low probability, because practically all the atoms are in definite places and only a few permutations are possible. On the other hand, a state of low order has many permutations because there are so many ways of arranging the atoms in the wrong places. At higher temperatures, therefore, a state of greater disorder is favoured because the increase in  $T\phi$  in the expression  $U - T\phi$  balances the increase in the internal energy  $U$  due to the disorder.

If an expression for the dependence of configurational energy and entropy,  $U_s$  and  $\phi_s$ , on the degree of order  $S$  can be formulated, the equilibrium state at the temperature  $T$  is given by

$$\frac{dU_s}{dS} - T\frac{d\phi_s}{dS} = 0.$$



The particular interest of the order-disorder change is that expressions for the entropy can be found. For instance, in the body-centred lattice considered above there is only one way of arranging the atoms in perfect order, and  $2^N$  ways of arranging them in disorder,  $N$  being the number of points on the lattice which may be taken to be that of one gram-atom of the crystal. Thus the relative probability of the two states is  $2^N/1$ , and by Boltzmann's theorem the entropy difference is :

$$k \log 2^N = Nk \log 2 = R \log 2 = 1.38 \text{ cal. per g.-atom per } ^\circ \text{C.}$$

The observed value of the entropy difference below the critical temperature can be calculated from Sykes' curve for the specific heat and turns out to be rather less—1.01 cal. per g.-atom—but, as will be seen below, a somewhat lower value is to be expected.

In calculating the dependence of the degree of order on the temperature, certain complications arise. In the Bragg and Williams calculations the degree of order was defined in terms of the proportion of  $A$  atoms on  $\alpha$  sites, and it was assumed that the difference of energy between right and wrong positions is proportional to the degree of order. This assumption led to calculations in qualitative agreement with observation, but it is clearly inadequate. It implies that the energy for a given atom depends on the average order of atoms in the whole lattice, whereas, owing to the short range of interatomic forces, the energy can only depend on nearest neighbours. Bethe recalculated the curves with a new definition of the degree of order depending on the number of correct neighbours. He deduced the existence of two kinds of order : long-distance order and short-distance or "liquid" order. The former implies a consistent set of  $\alpha$  sites for  $A$  atoms and  $\beta$  sites for  $B$  atoms all through the crystal. At the critical temperature long-distance order breaks down, but all order is not lost. It still remains true that each  $A$  atom has more  $B$  neighbours than  $A$  neighbours and *vice versa*, so that the structure is not completely random. There are numerous restricted regions of order in the crystal, but they are not in step with each other and their boundaries are in constant fluctuation. This explains the fact that the specific heat above the critical temperature is slightly above normal, for these localised regions are continuing to lose order as the temperature is raised. It also explains the fact that the measured entropy difference is somewhat lower than the calculated value, for some order is still left above the critical temperature. The existence of these two forms of order can be seen in a general way as follows : When order is nearly perfect, only a few atoms being out of place, it is clearly necessary to have a connected scheme of  $\alpha$  and  $\beta$  sites right through the lattice, with the majority of  $A$  atoms on the first and of  $B$  atoms on the second. On the other hand, when each atom has nearly as many wrong neighbours as right neighbours, the consistent scheme right through the crystal becomes, as it were, an irksome restriction. Far more permutations



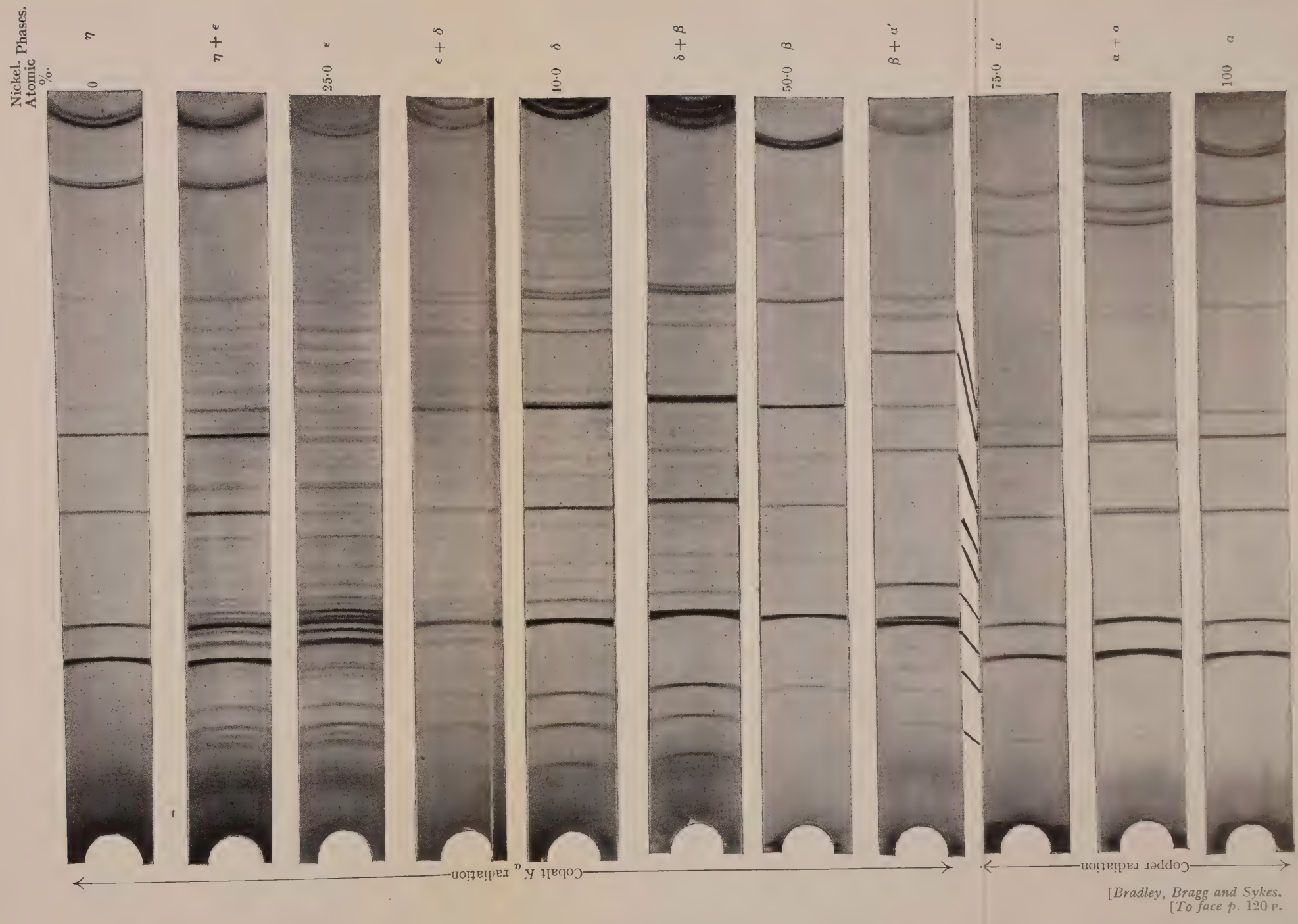


FIG. 20.—The Nickel-Aluminium System (*Proceedings of the Royal Society*, 1937, A, vol. 159, p. 56).

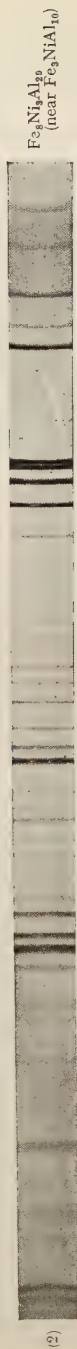
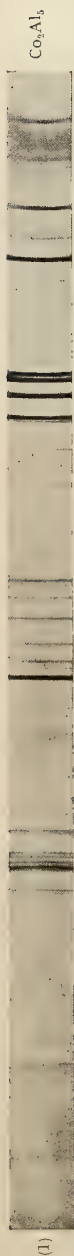


FIG. 21A.—A Comparison of the Powder Photographs of  $\text{Co}_2\text{Al}_3$  and  $\text{Fe}_3\text{NiAl}_{10}$  (*Journal of the Institute of Metals*, 1940, vol. 66, Plate XII.).

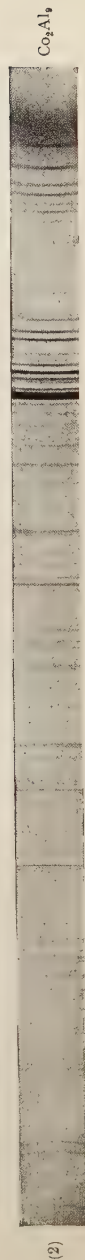
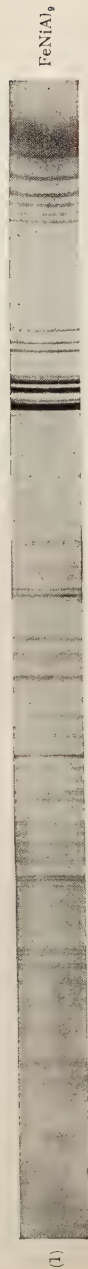


FIG. 21B.—A Comparison of the Powder Photographs of  $\text{Co}_2\text{Al}_3$  and  $\text{FeNiAl}_9$  (*Journal of the Institute of Metals*, 1940, vol. 66, Plate XII.).

(a) Quenched from  $850^{\circ}\text{C}$ .

(b) Quenched after one week at  $650^{\circ}\text{C}$ .

(c) Cooled from  $900^{\circ}$  to  $450^{\circ}\text{C}$ . at  $30^{\circ}\text{C}$ . per hr.

FIG. 22.—X-Ray Powder Photographs of  $\text{FeCu}_4\text{Ni}_3$  with different heat treatments.

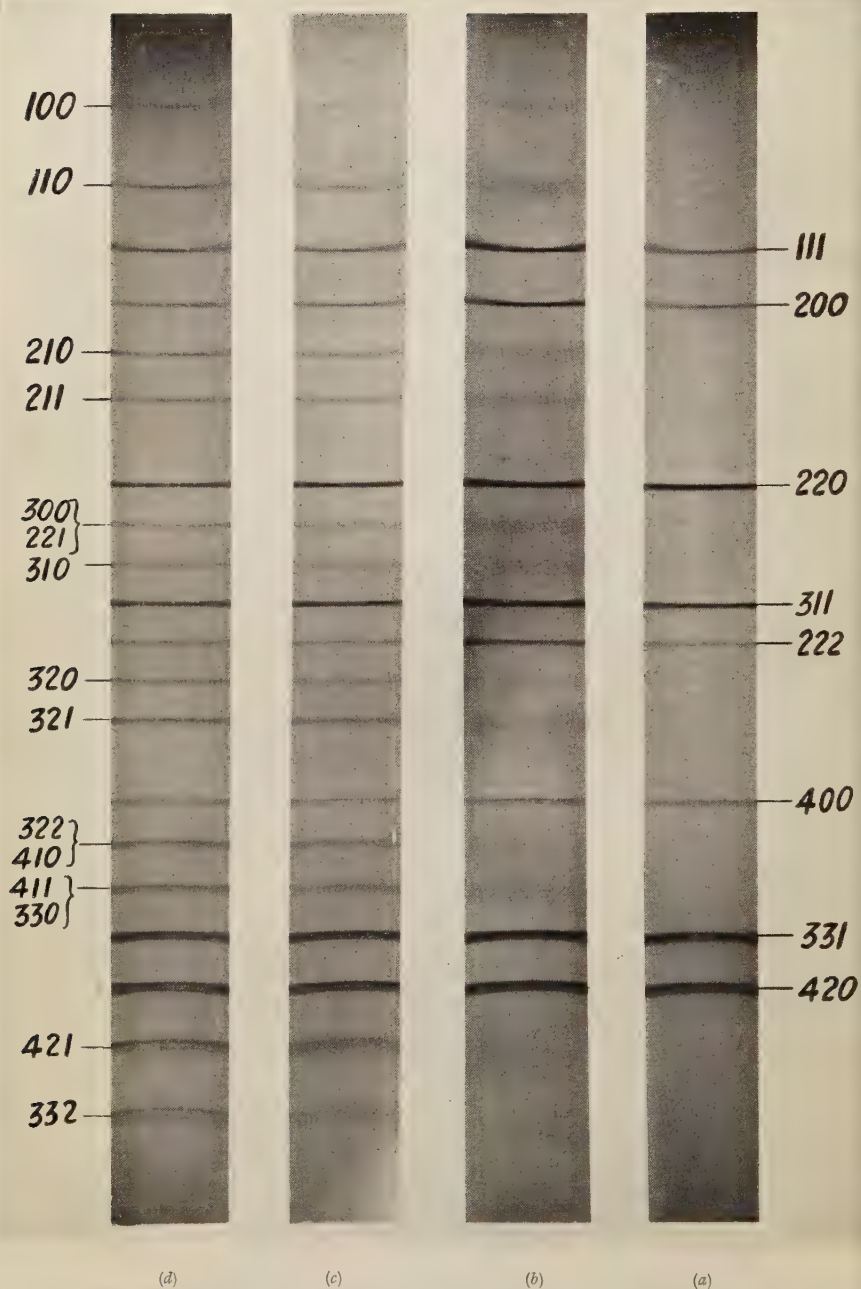


FIG. 23. —X-Ray Photographs of  $\text{Cu}_3\text{Au}$  taken with Copper  $K\alpha$  Radiation. Time of anneal at  $375^\circ\text{C}$ .:—(a) None (b) 12 min., (c) 500 min., (d) 6000 min. (*Proceedings of the Royal Society*, 1938, A, vol. 168, p. 376).

[Bradley, Bragg and Sykes  
[To face p. 121]



are possible if  $\alpha$  and  $\beta$  sites are interchanged at frequent intervals than if they remain in step. Hence the superlattice structure breaks up into a number of regions each consistent in itself. It may be compared to a highly organised society in a large kingdom in the first state, and a number of independent tribes in the other. The transition from one to the other takes place abruptly at the critical temperature.

The theory has been further developed by Peierls, Kirkwood and many others. The more recent calculations give a good agreement with the experimental results, and the whole forms an interesting example of the application of statistical mechanics to a problem of the solid state.

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Full references to the numerous papers by other authors will be found in Section A.

### Part II.—Experimental Work Concerned with the Order-Disorder Transformation and Allied Subjects.

By C. SYKES, D.Sc.

#### (1) Introduction.

In 1930, whilst engaged in a technical investigation<sup>(34)</sup> of the physical properties of the iron-rich iron-aluminium alloys, it was noticed that the electrical resistivity and coefficient of expansion of alloys in the region of  $\text{Fe}_3\text{Al}$  exhibited certain anomalies which could not be interpreted in terms of the then known thermal equilibrium diagram. The experimental results were discussed with Professor Bragg and Dr. A. J. Bradley, and an X-ray examination of the alloys was undertaken by Bradley and Jay.<sup>(35)</sup> They showed that in alloys approximating in composition to  $\text{Fe}_3\text{Al}$  atomic rearrangement occurred during cooling from  $700^\circ\text{C}$ ., the extent of the rearrangement being dependent on the rate of cooling and on the composition. For example, an alloy containing 25% of aluminium by atoms when



cooled at  $1^{\circ}\text{C.}$  per min. was found to have a perfectly ordered structure. The results of this X-ray work enabled a qualitative explanation to be given of the observed variations in the electrical resistivity and thermal expansion of the alloys.<sup>(36)</sup> In the meantime, Bragg and Williams<sup>(37)</sup> developed a theoretical treatment of the order-disorder transformation which not only explained in a qualitative way all the main properties hitherto observed during order-disorder transformations, but purported to predict the energy released in any alloy during the change from the disordered to the ordered arrangement.

It was clear, therefore, that an experimental determination of the energy released during such a transformation would enable a direct check to be made on the Bragg-Williams theory and its underlying assumptions. For various reasons the experimental technique normally used in the examination of thermal effects was not adequate for this purpose and a new type of apparatus,<sup>(38, 39)</sup> with suitable technique, was developed. This proved to be satisfactory.

The preliminary results<sup>(38)</sup> obtained were in good agreement with those predicted by the Bragg-Williams theory and a large field of profitable investigation became apparent. At this stage the Structure of Alloys Panel was formed and the work was carried out in conjunction with the British Iron and Steel Federation.

The present paper summarises the experimental work undertaken to provide a thorough check on order-disorder theory. It is shown that in certain transformations the theoretical treatment is adequate, but in others the transformations exhibit certain interesting effects not visualised in the theoretical treatment. Consideration of these effects has yielded much additional information about atomic rearrangement in metals. A short account is also given of the application of the new thermal technique to a number of other metallurgical problems, in particular to age-hardening transformations.

## (2) *Specific-Heat and Energy Measurements.*

The specific-heat/temperature (S.T.) curve of an alloy or metal undergoing a transformation consists of the normal S.T. curve with the effects of the transformation superimposed. The normal S.T. curve can usually be estimated, so that, provided that the modified curve can be experimentally determined, the energy involved in the transformation can be obtained from the difference in area between the two curves. Thus in Fig. 24 curve *OBXC* is an S.T. curve for the alloy  $\text{Cu}_3\text{Au}$  taken on heating; *OAD* is the S.T. curve which would be obtained in the absence of a transformation, and the area between the curves gives a measure of the total energy involved in the transformation.

In general, an experimental method which enables S.T. curves to be determined continuously over a large range of temperature is

to be preferred for the investigation of transformations. The standard calorimetric method which measures mean specific heat by the method of mixtures is unsuitable, since the quenching operation very often inhibits the transformation which is to be investigated. Aneroid methods are only suitable for the investigation of those transformations which take place so quickly in the temperature range under consideration that no lag occurs at the heating rate usually employed, and are useless in dealing with transformations in specimens in metastable equilibrium. The following outline deals with the principle of an experimental method which can be applied to a great diversity of transformations.

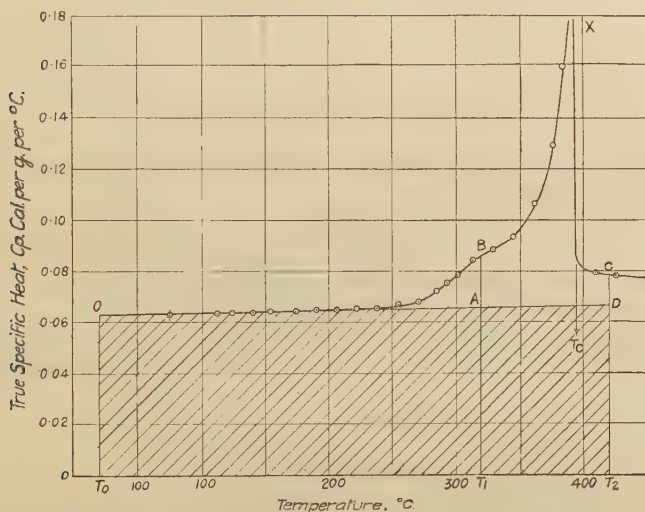


FIG. 24.—Specific-Heat/Temperature Curve of  $\text{Cu}_3\text{Au}$  after Cooling at  $30^\circ \text{C}$ . per hr. (*Journal of the Iron and Steel Institute*, 1938, No. II., p. 125P).

#### (a) Principle of Method.

The specimen, of mass  $M$  and specific heat  $S$ , is in the form of a closed hollow cylinder which can be heated internally by means of the coil  $C$ , see Fig. 25 (a). It is surrounded by and thermally insulated from a massive copper block  $B$ . This acts as a uniform temperature enclosure and can be heated by means of an external furnace at a uniform rate according to the curve  $T_{Bt}$ , Fig. 25 (b).

In the absence of any internal heating, the temperature of the specimen would follow a curve of the type  $T_{st}$  shown dotted. If a quantity of heat equal to  $Q$  cal. per sec., where :

$$Q > MS \frac{dT_B}{dt}$$

is supplied to the heating coil  $C$  the curve  $T_{st}$  will cross the curve  $T_{bt}$ . If then the heat supplied is reduced so that :

$$Q < MS \frac{dT_B}{dt}$$

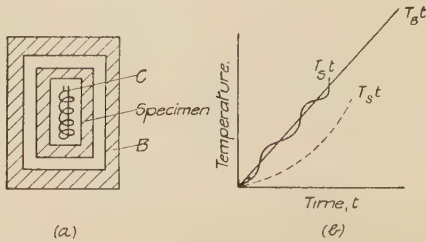


FIG. 25.—Specific Heat Apparatus (diagrammatic) (*Journal of the Iron and Steel Institute*, 1938, No. II., p. 125p).

the curve  $T_{st}$  will again cross  $T_{bt}$ . When the curves cross no heat transfer takes place and :

$$Q = MS \left( -\frac{dT_S}{dt} \right)_{T_S = T_B} \quad \dots \quad (1)$$

$S$  being the instantaneous specific heat at temperature  $T_S$ .

In practice  $(T_S - T_B)$  is always very small ( $< 0.5^\circ \text{C.}$ ), so that determinations of specific heat can be made at any temperature other than those when  $T_S = T_B$  by making a small radiation cor-

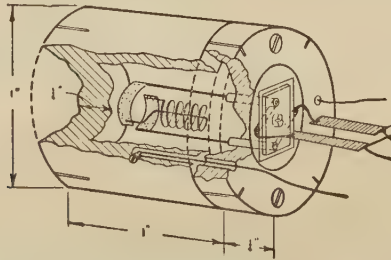


FIG. 26.—Detailed Assembly of Specific Heat Specimen (*Journal of the Institute of Metals*, 1937, vol. 61, p. 223).

rection,  $K$ , which can be determined experimentally, and we may write quite generally :

$$Q = MS \left[ \frac{dT_B}{dt} + \frac{d}{dt}(T_S - T_B) \right] + K(T_S - T_B) \quad \dots \quad (2)$$

Using equation (2), a complete S.T. curve such as  $OBXC$ , Fig. 24, can be obtained while the temperature is continuously varied.

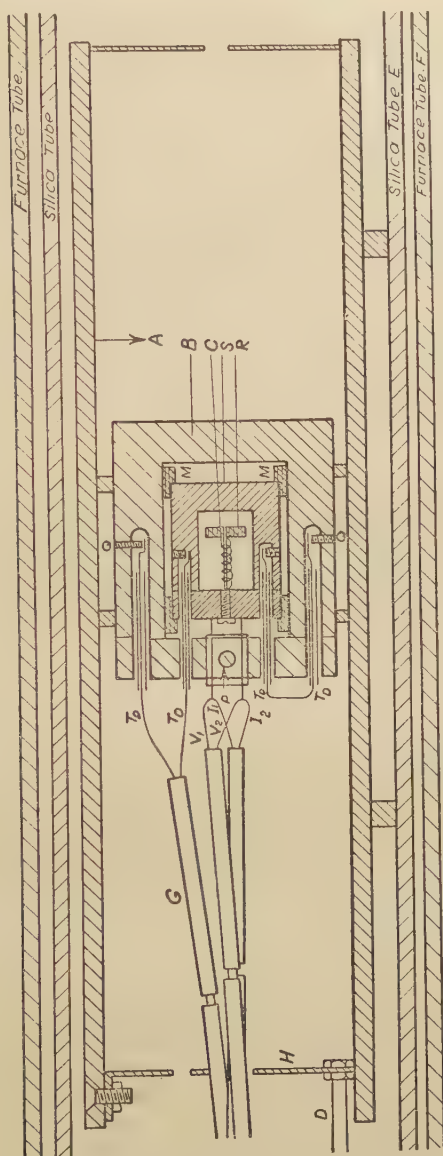


FIG. 27.—Internal Assembly of Specific Heat Apparatus (*Journal of the Institute of Metals*, 1936, vol. 59, p. 257). Scale = approx. half size.

(b) *Description of the Apparatus.*<sup>(39)</sup>

Fig. 26 gives the detailed design of the specimen, and Fig. 27 shows the assembly of the specimen and copper block in the copper





(3) *The Results of Thermal Measurements.*(a) *The Transformation in  $\beta$ -Brass (CuZn).*<sup>(40)</sup>

This transformation has formed the subject of a considerable amount of speculation, owing to the fact that it differs in certain essential respects from the more general type of transformation associated with a change of phase. According to the theory of Bragg and Williams,<sup>(37)</sup> the stable state of the alloy at low temperatures is an ordered one. The structure of the alloy is body-centred cubic; the copper atoms occupy the sites at the cube corners and the zinc atoms occupy the cube centres. On heating, the ordered structure becomes gradually less perfect, until at a certain temperature—the critical temperature—the arrangement of atoms goes over into an entirely random one. At each temperature there is a definite degree of order characteristic of the alloy in equilibrium. The structure remains body-centred at high temperatures, *i.e.*, there is no change of phase, but the one type of atom no longer appears to have any preference for a particular set of atomic sites. The disordering process is accompanied by an absorption of heat, so that the apparent specific heat of the alloy is abnormally high. A large drop in specific heat is expected after passing through the critical temperature.

In Fig. 29, (a) is the specific-heat curve obtained experimentally on an alloy containing 48% of zinc by atoms, whilst (d) is the curve expected\* in the absence of a transformation. The specific-heat curve (a) leaves the curve (d) at about 160° C., indicating that extra energy is being absorbed, *i.e.*, disordering commences. The rate of absorption increases until the critical temperature is reached at about 470° C.; here the alloy becomes completely disordered, and the specific heat drops back almost to the normal value. The rate of diffusion in  $\beta$ -brass is sufficiently high for the structure of the alloy to adjust itself without appreciable lag. It is clear, therefore, that the transformation extends over some 300° C. At any given temperature a dynamic equilibrium exists, just as many atoms leaving ordered positions per second owing to thermal vibrations as disordered atoms take up ordered positions.

In Fig. 29, (b) is the S.T. curve predicted by the Bragg-Williams theory and (c) is a theoretical curve derived by Bethe<sup>(41)</sup> from somewhat different assumptions. Bragg and Williams assume that the energy of a given structure is determined by the average degree of order throughout the whole structure, *i.e.*, by long-distance or superlattice order, so that the whole of the change in internal energy associated with the transformation takes place below the critical temperature. Bethe, on the other hand, assumes that interaction is limited to nearest neighbours, and shows that, whilst superlattice

\* Calculated from the known specific heats of pure copper and pure zinc, using the Kopp-Neumann rule.

order disappears at the critical temperature, a certain amount of local order exists above this temperature, since a tendency for unlike atoms to be neighbours still persists. Local order, according to Bethe, only disappears at very high temperatures, so that an abnormally high specific heat should exist even above the critical temperature.

From the curves shown in Fig. 29 it can be seen that the observed specific heat at the critical temperature is higher than that given by either theory, suggesting that the onset of the ordering process is more rapid than either theory would indicate. The precise form of

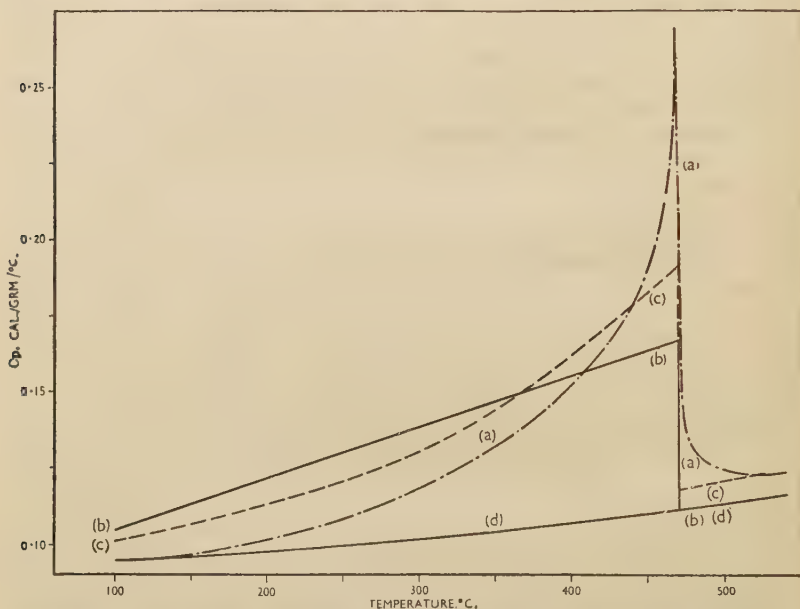


FIG. 29.—Comparison of Experimental and Theoretical Specific Heat Curves of  $\beta$ -Brass (*Journal of the Institute of Metals*, 1937, vol. 61, p. 223).

the S.T. curve depends very much on the assumptions made as to the relation between the energy and degree of order in the alloy, whereas the total change in internal energy and entropy are not so sensitive. The total energy of the transformation is 11.4 cal. per g. according to Bragg and Williams and 10.9 cal. per g. according to Bethe, and the experimental result is 9.8 cal. per g. The agreement is very satisfactory. By a slight modification of the theoretical relation between the energy and degree of order, Chang<sup>(42)</sup> has obtained a theoretical curve in good agreement with Fig. 29, (a). It will be noted that the specific heat of the alloy above the critical temperature is higher than would be expected, cf. Fig. 29, (a) and (d). The

difference is in satisfactory agreement with that predicted by Bethe's theory.

The  $\beta$  phase in the copper-zinc alloy stretches from 45.5%\* to 49.5% of zinc, the alloy of equi-atomic composition containing

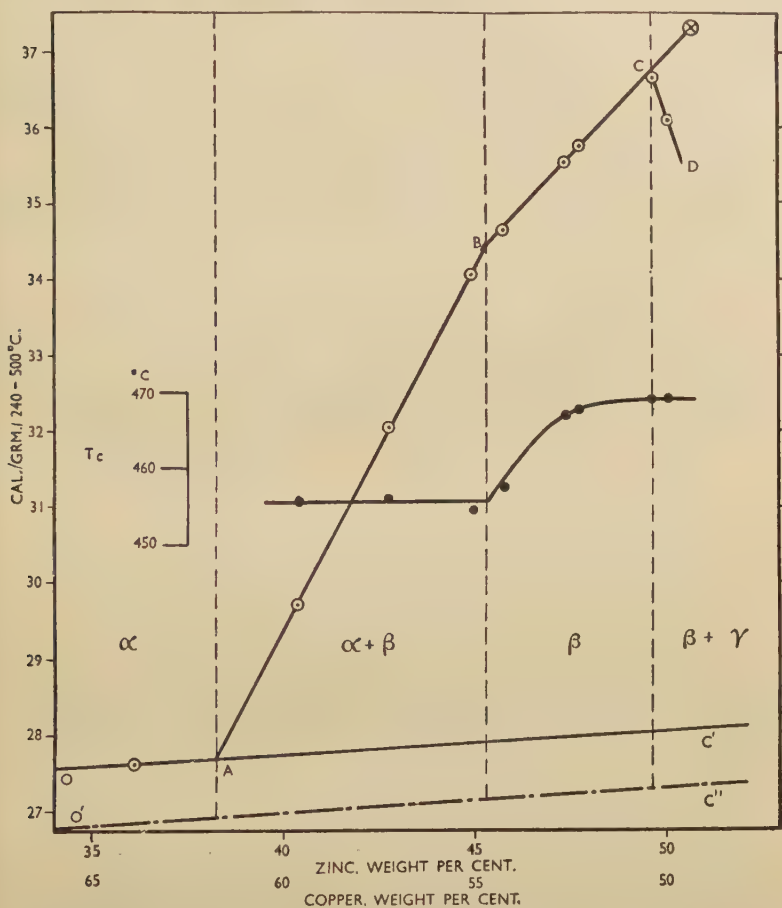


FIG. 30.—Energy Content and Transformation Temperature of  $\beta$ -Brass as a Function of Composition (*Journal of the Institute of Metals*, 1937, vol. 61, p. 223).

50.7% of zinc. A range of alloys in the  $\beta$  phase has been investigated to determine to what extent deviations from the equi-atomic composition affect the energy of the transformation. In Fig. 30,

\* Percentage by weight.

line  $ABC$  shows the variation with composition of the energy necessary to raise one gramme of an alloy through the temperature interval  $240-500^{\circ}\text{C.}$ , a range which substantially covers the order-disorder transformation. The line  $AC'$  gives the energy-composition curve expected in the absence of a transformation. The energy absorbed by atomic rearrangement is greatest for the alloy nearest to the equi-atomic composition. Easthope,<sup>(43)</sup> using Bethe's theory, has calculated the effect of concentration on the energy of the transformation, and finds that the ratio of the energies for the alloy at the extremity of the  $\beta$  phase poor in zinc and the alloy  $\text{CuZn}$  should be 0.78. The experimental result is 0.75.

Fig. 30 also shows the variation of critical temperature with composition, a fall of  $12^{\circ}\text{C.}$  taking place across the  $\beta$  phase. The calculated change according to Bragg and Williams is  $7.5^{\circ}\text{C.}$

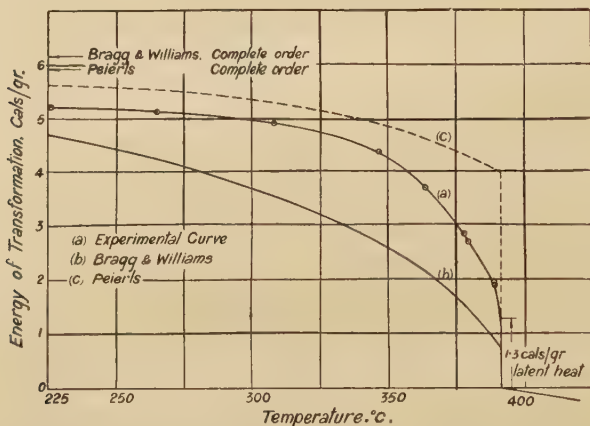


FIG. 31.—Comparison of Experimental and Theoretical Curves giving the Relation between Energy Content and Temperature for  $\text{Cu}_3\text{Au}$  (*Proceedings of the Royal Society*, 1936, A, vol. 157, p. 213).

#### (b) *The Copper-Gold Alloy $\text{Cu}_3\text{Au}$ .*<sup>(44-46)</sup>

The  $\beta$ -brass transformation may be considered typical of transformations in binary alloys  $XY$  of equi-atomic composition. It is particularly easy to investigate, since the atomic-rearrangement process occurs at great speed and no lag can be observed at heating and cooling rates of the order of  $1.5^{\circ}\text{C. per min.}$  Order-disorder transformations also occur in alloys of the type  $X_3Y$ — $\text{Cu}_3\text{Au}$ ,  $\text{Cu}_3\text{Pd}$ ,  $\text{Ni}_3\text{Fe}$ , &c. Such transformations have been found to be sluggish and can be inhibited by quenching from temperatures above the critical temperature.

The various theoretical relations between the energy of the order-disorder transformation and temperature relate to equilibrium

conditions and cannot be directly applied to metastable states. Special experimental methods\* were therefore devised which enable reliable information to be obtained of the manner in which the alloy  $\text{Cu}_3\text{Au}$  would behave if it could be retained throughout in equilibrium.

In Fig. 31, (a) is the equilibrium curve giving the energy of the transformation as a function of temperature for an alloy containing 24.9% of gold by atoms. Curve (b) is the theoretical curve according to Bragg and Williams, and (c) is a curve calculated by Peierls,<sup>(47)</sup> using Bethe's original assumptions; the values given by both theories for the change from complete order to the disappearance of superlattice order at the critical temperature are also indicated.

The precise shapes of the various curves differ to some extent, but the observed value for the total energy is in satisfactory agreement with the theoretical results. It is of interest to note that for alloys of type  $X_3Y$  both theories predict the occurrence of latent heat at the critical temperature, whereas for alloys of the type  $XY$  only a high specific heat is expected. Experiment confirms this distinction in the case of  $\text{CuZn}$  and  $\text{Cu}_3\text{Au}$ . An abnormally high specific heat is observed above the critical temperature in the case of  $\text{Cu}_3\text{Au}$  (see Fig. 24), indicating that the assumptions of the Bethe theory are a somewhat better approximation than those of the Bragg-Williams theory.

#### (c) *Other Transformations.*

Energy measurements have also been carried out on the alloys  $\text{Cu}_3\text{Pd}$ <sup>(48)</sup> and  $\text{Ni}_3\text{Fe}$ .<sup>(49)</sup> In both cases the rate of atomic rearrangement is very slow and annealing periods of several months' duration are necessary in order to prepare specimens with a high degree of order. The results obtained confirm the conclusions derived from the measurements on  $\text{Cu}_3\text{Au}$  and  $\text{CuZn}$ , namely, that the observed energy of the transformations is in good agreement with that predicted theoretically, slightly better agreement being obtained with the Bethe theory. A very high specific heat is observed at the critical temperature in the case of  $\text{Cu}_3\text{Pd}$  and  $\text{Ni}_3\text{Fe}$ , and no latent heat in contrast to the theoretical predictions. This could be ascribed to the marked sluggishness of these transformations.

It may be concluded, therefore, that the theories of the order-disorder transformation, and in particular that of Bethe, give a reasonably accurate quantitative account of the thermal behaviour of alloys during the atomic-rearrangement process.

#### (4) *Atomic Rearrangement Processes in $\text{Cu}_3\text{Au}$ .*<sup>(44-46)</sup>

##### (a) *Resistance-Temperature Curves.*

The change from the ordered to the disordered state affects not only the internal energy of an alloy but also other physical properties such as electrical resistivity, X-ray structure and so on.

\* Described by Sykes and Jones.<sup>(50)</sup>





ture is quite large:  $11.5 \times 10^{-6}$  and  $4.1 \times 10^{-6}$  ohms, respectively. By suitable heat treatment a variety of resistance-temperature curves can be obtained between the two extreme cases *ABOF* and *ABCD*.

Fig. 33 shows the resistance-temperature curve obtained on cooling from the critical temperature at  $30^\circ \text{C. per hr.}$  This rate of cooling is not sufficient to produce equilibrium, and the curve is higher than the equilibrium curve. The alloy freezes-in at about  $250^\circ \text{C.}$ , and the resistance decreases along the thin straight line produced to lower temperatures. If, after cooling to room temperature, the specimen is reheated at  $30^\circ \text{C. per hr.}$ , a resistance-

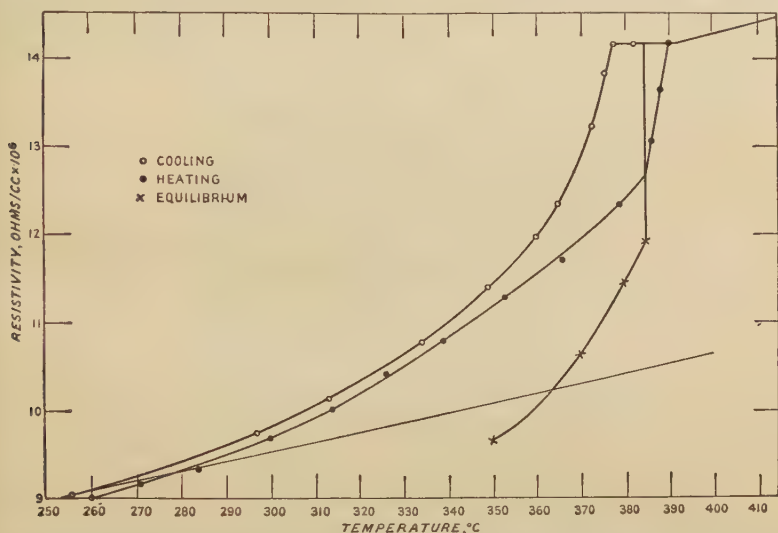


FIG. 33.—Resistance-Temperature Curves of  $\text{Cu}_3\text{Au}$  after Cooling at  $30^\circ \text{C. per hr.}$  (*Journal of the Institute of Metals*, 1936, vol. 58, p. 255).

temperature curve on heating may be measured. Since the alloy is by no means fully ordered, it would be expected that the heating curve would fall below the straight line at temperatures above  $250^\circ \text{C.}$  as the alloy relaxed towards equilibrium. Actually, the slope of the heating curve never becomes less than that of the straight line until the specimen is disordered. This means that the specimen, on the whole, continues to disorder throughout the heating cycle, although it is out of equilibrium in the opposite sense.

This very curious behaviour has been interpreted in the following way: The face-centred lattice of  $\text{Cu}_3\text{Au}$  is equivalent to four simple interpenetrating cubic lattices, see Fig. 34. In the completely ordered state the sites of one of the simple cubic lattices are entirely filled by gold atoms and the sites of the remaining

three lattices are occupied by the copper atoms. As the alloy cools through the critical temperature, gold atoms may segregate on any of the four lattices, and consequently any individual crystal will contain a large number of small domains or nuclei, each of which has its own consistent scheme of order. Neighbouring domains will be out of phase with one another and be separated by a boundary layer of disordered material. As the alloy cools, two effects occur simultaneously; the degree of order inside the domains increases and the larger domains grow at the expense of the smaller ones. This latter effect reduces the amount of disordered material and thus causes an additional lowering of resistance. In any particular domain the degree of order can follow the temperature relatively quickly, but the growth of domains is a much slower process, owing to the opposing forces of the neighbouring anti-

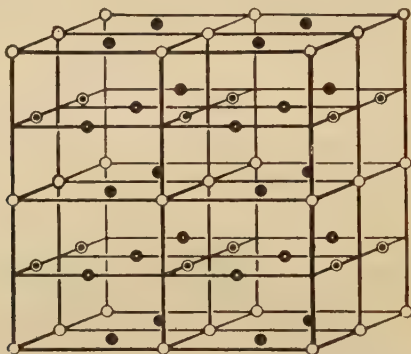


FIG. 34.—The Face-Centred Cubic Lattice of  $\text{Cu}_3\text{Au}$  shown as four interpenetrating simple cubic lattices.

phase domains. Reverting to Fig. 33, the growth of domains is only appreciable at temperatures above  $340^\circ \text{C.}$ , whilst below this the abnormal change in resistance with temperature is caused by the variation in the degree of order inside the domains.

If the alloy is maintained at a constant temperature the domains grow until the amount of boundary material becomes vanishingly small and the resistance attains the equilibrium value. For example, at  $O$ , a temperature of  $350^\circ \text{C.}$ , Fig. 32, the alloy is disordered. If quenched it has the X-ray structure characterised by the photograph in Fig. 23 (a)—*i.e.*, the structure of a disordered face-centred solid solution. If the specimen is annealed at  $350^\circ \text{C.}$  domains form and the resistance drops along  $OX$ . The X-ray structure as quenched after 12 min. is given by the photograph (b). The diffuse superlattice lines are produced by the small domains, and from the breadth of these lines it may be estimated<sup>(50)</sup> that the average size of the domains is  $50 \text{ \AA.}$  As the annealing time is increased the

superlattice lines become sharper, and after 500 min. the size of the domains is 280 Å., Fig. 23 (c). After 6000 min. the average linear dimension of the domains is greater than 1000 Å. and the resistivity of the alloy has fallen to the equilibrium value, Fig. 23 (d).

A fairly detailed study has been made of the effect of heat treatment on the properties of these antiphase domains and some of the conclusions will be indicated.

(b) *Annealing.*<sup>(44)</sup>

Suppose that one wishes to prepare a specimen of  $\text{Cu}_3\text{Au}$  in equilibrium at 250° C., starting from the initial condition that the specimen is above the critical temperature and fully disordered. A variety of heat treatments is possible, of which the two extreme cases will be considered. First, the specimen may be cooled rapidly to 250° C. and held there until equilibrium is attained. Domains form, having the equilibrium degree of order at 250° C., and then grow gradually. Measurements indicate that a period of 10,000 hr. would be necessary to attain equilibrium, the growth of domains at this temperature being so very slow. Otherwise the specimen can be cooled to a temperature just below the critical temperature, say, 375° C. At this temperature 50 hr. are sufficient to produce very large domains, and the specimen may then be cooled relatively rapidly, i.e., 30° C. per hr., to 250° C. and remain in equilibrium. By this second method therefore a total time of only 60 hr. is required to produce equilibrium.

This marked difference in annealing time is likely to be observed in all transformations in which equilibrium is achieved as the result of two processes one of which has a much longer period of relaxation than the other.

(c) *The Relation between Electrical Resistance and Size of Domains.*<sup>(46)</sup>

Reverting to Fig. 32 it is seen that the resistance falls along the line  $OX$  during annealing at constant temperature and simultaneously  $\epsilon$ , the size of the domains, increases. If the electrical resistance is plotted as a function of  $1/\epsilon$ , the number of boundaries per centimetre, a straight line results. Such a relation is to be expected in terms of the wave-theory of resistance, since the additional resistance introduced by the domain boundaries is caused by partial reflection of the conduction electrons. This effect will be proportional to the number of boundaries, i.e.,  $1/\epsilon$ . From the absolute value of the slope of the straight line estimates have been made of the reflection coefficient of the electron at the boundaries.

(d) *The Width of the Boundaries between Domains.*<sup>(46)</sup>

A considerable amount of experimental evidence has been collected which is consistent with the view that the boundaries between the domains or nuclei are very narrow, i.e., of the order

of one atomic distance or  $4 \text{ \AA}$ . As a typical example the variation in lattice spacing with nuclei size will be considered. Fig. 35 records the experimental results, and also certain values calculated on the assumption that each domain has the equilibrium degree of order throughout its volume and is surrounded by a layer of disordered atoms one atomic distance thick. The same hypothesis gives a similarly satisfactory interpretation of the change in internal energy and in intensity of superlattice lines with domain size. It can be concluded therefore with a reasonable degree of certainty that the boundaries are narrow.

This is an important result, since it indicates that the atomic forces must be short-range forces, and thus provides further confirmation that the basic assumption of the Bethe theory is correct.

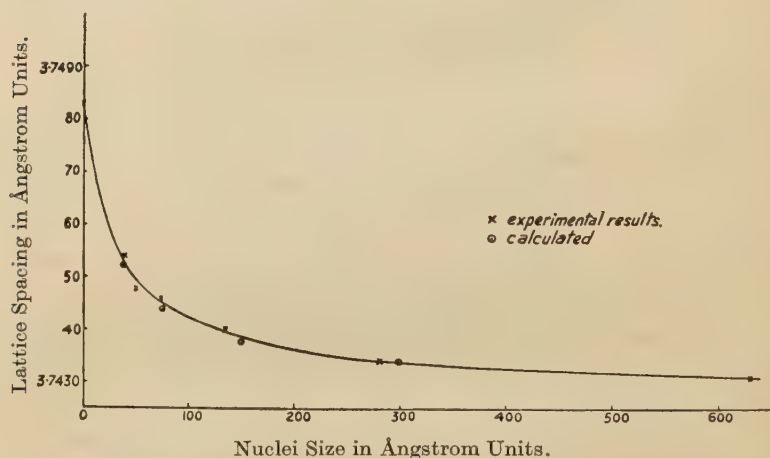


FIG. 35.—Lattice Spacing as a Function of Nuclei Size (*Proceedings of the Royal Society*, 1938, A, vol. 168, p. 376).

(5) *Detection of Superlattices in Binary Alloys of Metals having Similar Scattering Powers.*<sup>(49, 51)</sup>

Although the thermal work on  $\beta$ -brass pointed very definitely to the existence of an order-disorder transformation, the most direct form of evidence—the presence of superlattice lines on X-ray photographs—was lacking. The scattering powers of copper and zinc are almost identical, owing to the fact that the elements differ by only one unit in atomic number, and under ordinary conditions the relative intensity of the superlattice lines compared with the main lattice lines is so weak as to render them invisible against the general background obtained on X-ray photographs. In view of the importance of the transformation, further efforts have been made to detect the presence of a superlattice in this alloy.



Use was made of an effect, first employed by Bradley and Rodgers,<sup>(52)</sup> that an anomalous diminution in scattering power occurs when an atom is irradiated by a wave-length very near to that corresponding to its own absorption edge. In this way an additional differential effect was obtained using zinc radiation, leading to a calculated increase of six times in the intensity of the superlattice lines. A camera having a large dispersion was used to reduce the relative intensity of the background. All the superlattice lines up to  $\Sigma h^2 = 9$  were observed and shown to occur in exactly the right positions. This work confirms conclusively that the  $\beta$ - $\beta'$  transformation in brass is an order-disorder transformation.

In a similar manner satisfactory experimental evidence has been obtained which shows that an order-disorder transformation occurs in  $\text{Ni}_3\text{Fe}$ . In this case, the transformation takes place very slowly, and annealing periods of several months were required to produce a highly ordered alloy. Monochromatic cobalt  $K_\alpha$  radiation was used in preparing the X-ray photographs. Haworth<sup>(53)</sup> has recently confirmed this experimental result.

The fact that an order-disorder transformation takes place in  $\text{Ni}_3\text{Fe}$  is of interest, since it may have some bearing on the remarkable magnetic properties of alloys of the permalloy type.

#### (6) *Thermal Work on General Problems.*

The thermal technique originally developed for the investigation of the order-disorder transformations has been used to determine the specific-heat/temperature curves of iron and nickel.

##### (a) *Specific-Heat Measurements on Iron and Steel.*<sup>(54)</sup>

From time to time various anomalies have been noted in the physical properties of iron as a function of temperature. Naeser<sup>(55)</sup> reported specific-heat measurements which purported to show that a number of transformations occurred below the magnetic change point even in pure iron, and he suggested that these transformations might be associated with the other observed anomalies. In order to check this claim, measurements of the specific-heat/temperature curve from  $100^\circ$  to  $450^\circ$  C. were made on a representative selection of commercially pure irons and plain carbon steels. The resulting curves showed no anomalies greater than the expected experimental error, and gave no support for Naeser's conclusions. Measurements<sup>(56)</sup> of the temperature coefficient of resistance as a function of temperature were also made, using a number of the materials previously investigated by thermal methods. Again no marked discontinuities were observed. It appears therefore that the anomalies in mechanical properties observed in the temperature range  $100$ – $400^\circ$  C. should not be ascribed to hypothetical periodic changes in the fundamental character of the element iron, but rather that the explanation should be sought from a consideration

of structure-sensitive factors such as cold-work, grain size, precipitation-hardening, &c.

(b) *Specific-Heat Measurements on Pure Nickel.*<sup>(57)</sup>

Various theoretical formulæ have been derived correlating electronic energy, magnetisation and temperature, and such relationships are readily checked once accurate data are available giving the variation in specific heat of a ferromagnetic material in the neighbourhood of the Curie point. Numerous experimental investigations of the specific-heat/temperature curve of pure nickel have been made from time to time, but the results are not in very good agreement. Using the thermal technique described in the present paper, measurements were made of the S.T. curve of four representative types of "pure" nickel, and the results were critically examined and compared with those obtained by previous workers. A most probable S.T. curve was derived for pure nickel which is sufficiently accurate to enable a reliable check to be made on the various predictions of ferromagnetic theory.

(7) *Age-Hardening Processes.*<sup>(60)</sup>

The physical properties of a large number of commercial alloys are enhanced by heat-treatment processes referred to as age-hardening or precipitation-hardening. All such alloys are characterised by the fact that the solubility of the "hardening" constituent in the parent solid solution increases with temperature, and the heat treatment is usually carried out in three stages: A solution treatment at a high temperature which ensures that a saturated solution is formed, a quench retaining the hardening constituent in solution, and an ageing treatment at a fairly low temperature during which the supersaturated solution commences to break down. It is during this final process that the improvement in physical properties is achieved. Maximum hardness is usually obtained before any precipitate can be detected by microscopical methods.

Various theories of the age-hardening process have been put forward from time to time; according to Merica,<sup>(58)</sup> the hardened alloy contains a very finely divided precipitate, too small to be detected by microscopical methods; according to Gayler,<sup>(59)</sup> the hardened alloy is characterised by the segregation of the solute atoms on the parent lattice. When precipitation takes place from a supersaturated solid solution heat is evolved, and it appeared that, provided that sufficiently sensitive thermal measurements could be made, they could be used as a criterion of the extent to which precipitation had occurred in an alloy during a given ageing treatment. Thermal and hardness measurements were made on five typical age-hardening alloys, and the conclusions will be illustrated by means of the experimental results obtained from a silver-

copper alloy containing 7.5% of copper and an aluminium-copper alloy containing 4.8% of copper.

Fig. 36 gives the results obtained on the silver-copper alloy. All the S.T. curves were taken at a heating rate of  $2^{\circ}\text{C. per min.}$  Curve (a) is the S.T. curve of the alloy taken on the alloy as slowly

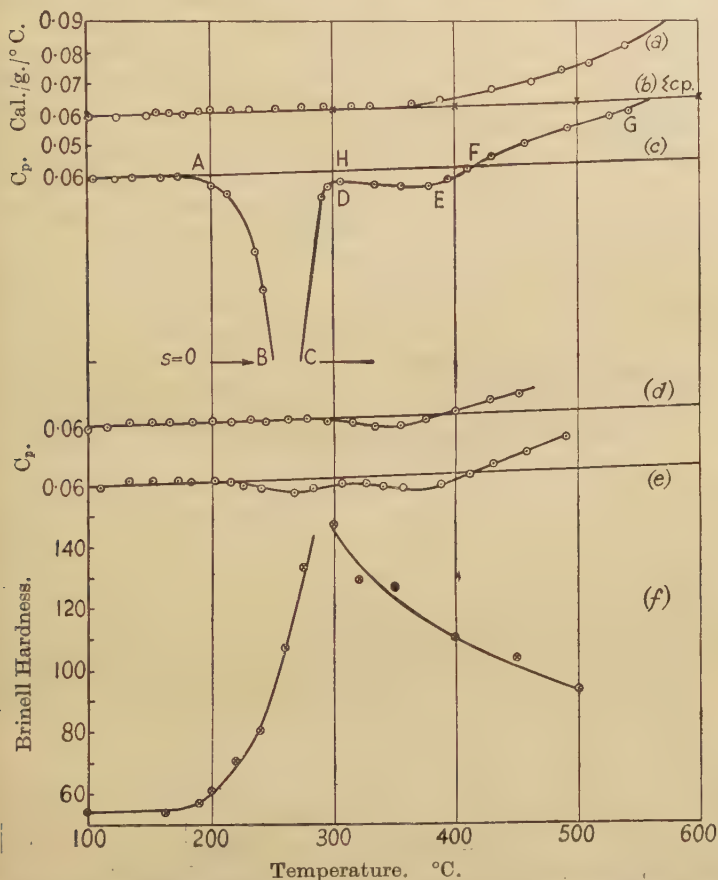


Fig. 36.—Specific-Heat/Temperature Curves and Hardness-Temperature Curves of Silver-Copper Alloy (*Proceedings of the Royal Society*, 1938, A, vol. 168, p. 237).

cooled. Up to  $360^{\circ}\text{C.}$  it is in good agreement with curve (b), which was obtained by calculation, assuming that the alloy behaved as a pure mixture. Above  $360^{\circ}\text{C.}$  the curves diverge, indicating that extra energy had to be supplied to effect solution of the copper.

Fig. 36 (c) is the S.T. curve obtained on the alloy as quenched

from 760° C. Between *A* and *D* a considerable amount of energy was released, suggesting that precipitation was taking place.

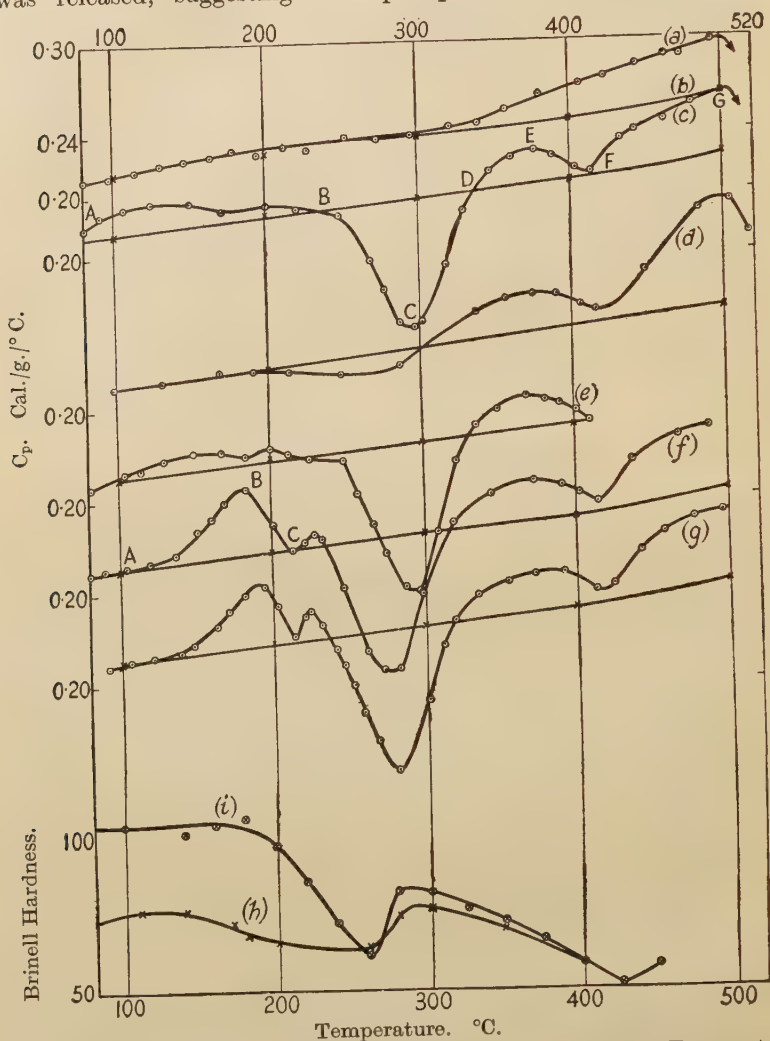


FIG. 37.—Specific-Heat/Temperature Curves and Hardness-Temperature Curves of Aluminium-Copper Alloy (*Proceedings of the Royal Society*, 1938, A, vol. 168, p. 237).

Curve (f) is a hardness-temperature curve taken under experimental conditions comparable with those used in the experiment recorded in curve (c). Maximum hardness occurred at about

300° C., when the major portion of the chemical energy associated with the precipitation process had been released. Curves (*d*) and (*e*) are S.T. curves obtained on specimens age-hardened for 30 min. at 300° C. and 13 hr. at 200° C., respectively. They confirm that at maximum hardness nearly all the energy had been released, *i.e.*, precipitation is practically complete.

Fig. 37 gives the results obtained on the aluminium-copper alloy. Curve (*a*), obtained on the slowly cooled alloy, when compared with curve (*b*), the calculated curve, indicates that re-resolution of the solute phase sets in at about 300° C. Curve (*g*) is the S.T. curve obtained on a specimen which had been fully hardened by ageing for 22 hr. at 140° C., and should be compared with curve (*i*), which is the corresponding hardness-temperature curve. It will be noted that extra energy has to be supplied to the aluminium-copper alloy in the temperature range 100–220° C. before the energy of precipitation can be released in the interval 240–320° C. From this it can be deduced that in the hardened alloy the copper atoms are segregated into islands on the aluminium lattice, but that no precipitation or breaking away of the solute phase has taken place.

The above experimental work confirms that both theories relating to the hardened state are applicable, but that in different alloy systems different structures are to be associated with maximum hardness.

Much further work will be necessary before the age-hardening processes are fully understood, and detailed examinations of a number of systems have been commenced. The specific-heat work is being complemented by X-ray investigations. It appears that present X-ray technique is capable of deriving much useful information about the precise structure of hardened alloys, and experimental work already concluded <sup>(61)</sup> has shown that the precipitate in certain alloys can be detected by X-ray methods at stages in the hardening process prior to maximum hardness.

#### *Acknowledgments.*

The research work summarised in Part II. has been carried out by the following able and enthusiastic collaborators: H. Evans, Assoc.Met., F. W. Jones, Ph.D., H. Wilkinson, Ph.D., P. Leech, M.Sc., and N. Swindells, Ph.D.

The work on age-hardening was carried out in co-operation with Professor R. S. Hutton and Dr. Stockdale, of the Metallurgical Laboratories, Cambridge.

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of Dr. A. P. M. Fleming, C.B.E., Director of Research, Metropolitan-Vickers Electrical Co., Ltd.

Finally, the general programme of researches has been controlled by the Structure of Alloys Research Panel, under the able chairmanship of Dr. W. H. Hatfield, F.R.S., the supervision being undertaken by Professor W. L. Bragg, F.R.S.

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*DISCUSSION.*

Dr. W. H. HATFIELD, F.R.S. (Vice-President, Sheffield), in opening the discussion, said that Professor Bragg's clear explanation of the work and his evident enthusiasm for the subject emphasised how fortunate the industry had been in securing the collaboration of the pure scientists concerned with industrial investigators. Pure science had gone ahead a very long way on its own, entirely detached from industry. Dr. McCance had said that morning that theory was getting nearer and nearer to the art of steelmaking. Curiously enough, in most industries, though not in all, the art, the way of doing a thing, had developed by trial and error, and then the scientist hurried along as fast as he could, trying to catch up and to explain what had been achieved by trial and error. The fundamental idea of the collaboration with the school that Dr. Bragg had created and the work of Dr. Hume-Rothery and others—"not forgetting," Dr. Hatfield added, "some of our own work"—was to be able to give intelligent guidance to the industry, so that progress might be achieved more rapidly than in the past, not so much by trial and error (a slow and costly process) but because one knew why one was doing things. If it was possible by the assistance of schools of purely scientific men, working on fundamentals, to produce a system of law which would act as a guide, then he was sure that it was worth all the support that the industry could give to such work.

In order to emphasise to industrialists who were responsible for the development of industry on the industrial and economic rather than the scientific side how useful were such fundamental methods of attack, he would mention that some fifteen or sixteen years ago he was concerned with experiments on austenitic rustless steels, and it was found that by cold-working those steels it was possible to obtain great strength in addition to rustless properties. One of the virtues of those austenitic steels, however, lay in the fact that they were non-magnetic, but when cold-worked to produce great strength, though they did not lose their rustless properties, they did become magnetic—a most mysterious thing. Unfortunately in those days in Britain they had not the means of attack by the X-ray method, and he therefore got into touch with Dr. Benedicks, of Stockholm, who was successful at the first attempt in showing that the reason why the non-magnetic material became magnetic as a result of cold-work was simply that the cold-work toppled over the face-centred cubic system to the body-centred. That was really of great industrial use, because it showed what the position was and made it possible to take steps to see what should be done next. That was an instance of the practical value of that line of attack.

The last time he had visited Professor Bragg at the Cavendish Laboratory he was told that the investigators were now tackling cementite. That was of very great interest. It was a strange thing

that at this time in the history of the Iron and Steel Institute, with an industry so old, an industry which had relied on adding carbon to iron to obtain all the improved properties necessary, they really did not know what cementite was. He thought Professor Bragg would agree that that was no exaggeration.

Professor BRAGG interposed that Dr. Lipson had completed his investigation of cementite the previous week and, in his (Professor Bragg's) opinion, had definitely established the structure.

Dr. HATFIELD remarked that that was splendid. That led him to ask for another piece of work to be done. When the investigators had established what cementite was—and that really applied essentially to structure—they would not by that process have altered its properties; but perhaps they might be able to explain why it was that when soft, ductile iron—malleable iron—was sprinkled with little nuggets of hard, brittle, friable cementite carbide, the strength of that soft, ductile iron increased. That was the sort of problem which it was hoped to solve as a result of the authors' investigations. The authors could not, however, make further progress to the extent desired for the practical assistance of the industry without the utmost collaboration on the part of the industry. It was disclosed in the paper, for instance, why the 30% nickel, 12% aluminium balanced iron alloy had a very high coercive force, and that could not have been predicted by the previously known laws. It was necessary to hand over to Professor Bragg and other such investigators the fundamental, out-standing technical facts, and they would match those facts with the basic phenomena which they disclosed by their delightful method of attack.

Dr. H. LIPSON (Cambridge) said he had been working with Mr. N. J. Petch on the structure of cementite, which Dr. Hatfield had just mentioned. The methods of working out simple structures like cementite were fairly well established, and the only difficulty with cementite was the small weight of the carbon atoms. Iron was about four times as heavy as carbon, and since there were three iron atoms to each carbon atom the carbon affected the X-ray intensities only slightly. Previous investigators—Hendricks in America and Westgren in Sweden—had agreed on the positions of the iron atoms. Hendricks found these first of all and suggested certain plausible positions for the carbon atoms, but did not attempt to see whether his X-ray intensities agreed with them. Westgren repeated and verified his work, but suggested that the positions assigned to the carbon atoms were less plausible than some others which he (Westgren) suggested. He also attempted to show that his X-ray results agreed better with the second structure, but was careful to state that they could not be regarded as giving definite confirmation.

When he (Dr. Lipson) became interested in the matter he did a few calculations and found that, although at the Cavendish Laboratory they claimed to measure intensities as accurately as anyone else, the contribution which the carbon made to the intensities was of about the same order as the experimental error—always a doubtful position for a physicist to be in. That meant that it was necessary to take the whole consensus of opinion of all the intensities, rather than any one in particular. One in particular could not give very much information, but the whole lot, if it were possible to get a kind of “mass observation” of all the intensities, might tell a coherent story.

The method of doing that was Fourier synthesis, which Professor Bragg had made practicable about twelve years ago. A three-dimensional Fourier synthesis of this structure showed very beautifully a small peak of the right size at almost exactly the position which Westgren proposed for the carbon atoms, whereas at the position which Hendricks proposed there was only a very small peak. It was thus established that the structure put forward by Westgren was really the right one. It was proposed to publish these results in more detail in the near future.

With regard to the paper under discussion, he would like to emphasise the importance of the use of the free-energy concept in deducing phase diagrams. The idea was first proposed to the Institute in the year 1900 by Roozeboom, who showed how all the different types of phase diagrams could be produced, but it had not been used as it might have been. By using that method it was possible to get rather more theoretical detail than by using the phase rule only. On the other hand, some of the generalisations which were accepted in phase diagrams seemed to have no theoretical justification. For example, it did not follow that the maximum melting point of an intermetallic compound in a phase diagram should have the exact formula of that compound, although many people seemed to take this for granted. It was on lines such as those that the more general use of the free-energy concept would be of value in this type of work, and the authors had used it in getting the detail of the ternary and binary diagrams theoretically sound.

Dr. A. H. JAY (Stocksbridge, near Sheffield) said that it was clear that the paper had added much to the knowledge available on a number of binary systems. The striking ones were probably the iron-nickel and chromium-aluminium systems. The work on the constitution of the ternary alloys could only be described as brilliant both in tactics and in execution, particularly when regard was had to the small number of alloys which served to fix so many solubility boundaries. One would look forward to further results with those structures which were too small to be resolved by the microscope.

Dr. Sykes' specific-heat work was made profitable by the



development of a first-class experimental technique, and the X-ray investigation which Dr. Sykes had carried out on the copper-gold alloys was also profitable, because it revealed a discriminating insight into the possibilities of atomic recrystallisation.

It was probably inevitable that a paper which had to summarise so much specialised X-ray work must present a fairly tough proposition to the average reader, and he himself had found it "tough" at times, in trying fully to understand it. He would suggest that the authors should risk telling again and again the story of how X-rays were used in analysing solids, metallic and non-metallic, and that they should give the information in a way suited to those who were going to receive it; they should repeat their story until the potentialities of the X-ray method were as clearly understood as those of chemical analysis or mechanical tests. He believed that that was a very urgent need.

DR. WILLIAM HUME-ROTHERY, F.R.S. (Oxford), described the authors' work as a superb piece of research which had opened up so many subjects that it was possible to comment on only a few of them. Dr. Bradley's work in general could be divided into two sections: The determination of the structures of the phases, and what might be called the further attempts to incorporate the structures of the phases into the diagrams given. So far as the first of these was concerned, the work was outstanding and unequalled; with regard to the work on the diagrams, it was probably not unreasonable to say that there was a certain distrust between the X-ray workers on the one hand and workers using the older methods on the other. That was unsatisfactory, because each could contribute a great deal. The discussion of the present work before the Institute enabled ordinary metallurgists to see the heights to which X-ray workers had led them, and how far they could go, whilst if the metallurgists raised their objections, the X-ray physicists would be enabled to see the reasons for the rather general atmosphere of distrust which existed.

It was a little difficult to discuss the diagrams, because the authors had frankly admitted that they were setting out to make a preliminary sketch only; the diagrams must therefore be accepted as they stood, and discussed within the authors' own limits. In his Introduction, Professor Bragg said: "Chemical analysis is essential, because the mechanical properties of metals are influenced in a fundamental and complex way by even small proportions of certain elements." It might be added that in the case of iron, at any rate, the structure of the alloy was also affected, and the X-ray physicist could do much to disarm suspicion if he would give the composition, not of the lumps of the alloys which he used for his work, but of the actual filings used in his experiments. There seemed to be some reluctance to give information of that kind, yet in preparing filings the substance might oxidise, it might take in



nitrogen, and in dirty towns such as London and Manchester it might take up carbon from the air; the extent to which dirt could get into filings was astonishing. If one determined the iron, the nickel and the aluminium in a typical alloy would one get a total of 99.5, 99.9 or 99.99%? Experience at Oxford was that with filings prepared by ordinary methods in air, 99.5 or 99.6% could be easily obtained, but to go higher than that special precautions had to be taken.

The second point in connection with the composition arose from the new methods which Dr. Bradley and his collaborators had devised for determining tie-lines in alloys from the relative amounts of two phases. The general theory was very straightforward: One took the X-ray photograph, which had the lines corresponding to two phases in the alloy selected, one estimated the relative amounts from the intensities of the lines, and there was the answer; but again it was clear that the essential thing was the composition of the final fine-sieved filings which were used, and in some cases one got into great difficulties. At Oxford they had taken alloys which consisted roughly of equal amounts of two phases, filed them up and analysed the fine filings, and there had been almost 100% of the one phase. It would be interesting to know, therefore, what precautions were taken to avoid errors of this kind; it was difficult to see how errors could be avoided unless the fine filings were analysed, or a large number of alloys was examined so that discrepancies showed up. To what extent did the authors' findings depend on the assumption that the fine filings were of the same composition as the main lump?

With regard to the ternary equilibrium diagrams, taking the ternary system iron-nickel-aluminium, aluminium had a melting point of 650° C. and iron and nickel melting points of about 1500° C., so that if the alloys were slowly cooled one would expect the equilibrium to "freeze" at the aluminium end at a much lower temperature. It seemed unreasonable, therefore, to claim that the diagrams were equilibrium diagrams; there was a general shift the whole way down the diagram towards a lower temperature at the aluminium corner. Moreover, the complex changes which occurred would in general proceed with very different velocities, and in particular the simplest superlattice changes which involved atomic movements of only one or two atomic diameters would proceed much faster than the normal processes involving diffusion over larger distances. Some of the phases, therefore, would correspond to one temperature, and some to another, and he thought it would be fair to describe the diagrams as constitutional diagrams, rather than to imply that there was anything in the nature of equilibrium in them. They seemed to him to be essentially constitutional diagrams of alloys prepared under arbitrary conditions. Within those conditions they were satisfactory; on the other hand, those conditions varied very much.

It seemed not unfair to say that the authors' general conclusion in their paper was that the X-ray methods offered an easy way of determining constitutional or equilibrium diagrams with relatively few alloys. He thought that that was a rather misleading impression. Dr. Bradley, who had a genius for the work, might be able to see the tiny clues which indicated when one might be led astray, but in general it was a mistake to suggest that the X-ray method could take over the work of making equilibrium or constitutional diagrams from the older methods. Each had its own sphere, and the metallurgical staff of the National Physical Laboratory, who were experts in the use of the microscope, would probably obtain the same results as Dr. Bradley—whether faster or slower was a matter of opinion. Dr. Bradley had perhaps placed a false emphasis on the potentiality of his method, the real advantage of which was that it enabled the tie-lines to be obtained accurately. On the other hand, it would be of assistance if the authors would give a little more information as to how the tie-lines in their diagrams were obtained. In some cases they were obviously soundly obtained, but in others they looked rather like optimistic hopes, as when one found tie-lines across a whole two-phase area and one single alloy, or perhaps two alloys, in that whole area. It would help to make the authors' work accepted more generally if they would describe their methods more fully and if in the diagrams they would distinguish more clearly between what was certainly established and what might be called an optimistic hope.

The authors' work showed the immense powers of the X-ray method and the field to be explored, but it also showed that the X-ray physicist and the classical metallographer must no longer work in isolation, but must co-operate. If the work described was to be continued as a general programme of steel research there must be real collaboration between the two sides.

Mr. D. A. OLIVER (Sheffield) characterised the paper as an admirable one, in that it brought together for the busy industrialist a vast amount of work and described the up-to-date technique employed. The great importance of the paper probably lay in the fresh ideas which were brought to the notice of those who were engaged in everyday work, such as the nature of the order-disorder transformation, the possible occurrence in a lattice of vacant sites, which was very important and, he thought, an entirely new idea, and the nature of incipient precipitation, which could not be over-emphasised in connection with age-hardening, because precipitation phenomena occurred not only in non-ferrous alloys but also in steels. Another very important point was the need to survey a wide field of composition if one was interested in the addition of very small percentages of a further element. That was brought out very beautifully in the aluminium-rich end of Fig. 12B, where one would be lost without a survey of a very much wider field.

Dealing with the power of the new method, he had been interested in the system iron-nickel-aluminium in connection with the fact that it contained within its boundaries the Mishima class of permanent-magnet alloys, and those alloys were most difficult to investigate microscopically. He did not say that it was not possible to get any indication microscopically, but it was impossible to do much at all critically. That was borne out by the work of Köster, who derived an entirely wrong diagram by very painstaking microscopic work on classical lines. That was an interesting example of the application of the new method to a system which from the microscopical point of view was recalcitrant. On the soft magnetic materials he thought that the work of Dr. Sykes was very much to be welcomed, and particularly the work on Permalloy. The new information, obtained after a great deal of trouble, was most important in attempting to understand the remarkable properties of that alloy.

It might be asked how the authors' work affected ferrous metallurgy in general. The work was a necessary foundation, and we were now on the threshold of having it extended to systems containing carbon, which would do far more than add just one more element. From what Dr. Lipson had said, cementite had been a difficult structure to solve, and that was only the start of a vastly more complicated set of problems. Further work of the same superlative character would be eagerly awaited, and even those who had to spend most of their time on industrial problems appreciated the work in pure science which the authors had done. The new X-ray method was to be welcomed on account of its speed, its certainty, and the ease with which the number and character of the phases present could be determined. In the speaker's own laboratory X-ray examination had already proved of considerable value. It was realised that for identifying phases in the fully annealed condition the powder technique was unrivalled, but most industrial problems involved searching comparisons between used and unused specimens, coupled with the high desirability of being able to carry out microscopical and X-ray observations on the same specimen. Generally, the differences were so small that cold-working the specimen by filing followed by a complete re-heat-treatment was not permissible on account of unavoidable variations. It was known, for instance, that certain features of a cold-worked material were not necessarily wholly removed by repeated heat treatment. Were the authors able to predict any likely considerable improvements in glancing angle and back-reflection technique to enable such problems to be effectively solved, at the same time satisfying the conditions laid down above?

Dr. ANDREW McCANCE (Member of Council, Glasgow) advised his fellow-Members to pay great attention to the work emanating from the Cavendish Laboratory in future, because as time went on it

would touch their everyday work more and more closely. Many of them had been aware for some time that the ordinary methods of thermal, mechanical and metallographic analysis had rather exhausted their possibilities as they were known at present, and had felt that behind the structures which could be seen under the microscope there was a region which exerted a profound effect on the physical and mechanical properties of the metals with which they were dealing every day. He was sure, therefore, that they witnessed in the present paper one of the first contributions, so far as the Iron and Steel Institute was concerned, to a new technique which would become of increasing industrial importance.

As the paper was a record of facts it was somewhat difficult to discuss, but there was one aspect of the order-disorder change on which he would like to put a question to the authors. Other speakers had drawn attention to the close similarity between the order-disorder change and magnetic properties, and Dr. Hatfield and Mr. Oliver referred to the fact that in the nickel-aluminium alloys the reason for the high magnetic values was discovered only when the X-ray technique was applied. He thought that its importance in the practical development of magnetic alloys had not yet reached its limit; he believed that the platinum-iron alloy in an ordered state had a coercive force in the region of 1400, which was the highest value achieved so far, and he was sure that as the work progressed and more information was obtained, further important magnetic alloys would be obtained.

The similarity between the magnetic and the order-disorder change was a very close one. The change in specific heat, for instance, depended on the same differential of  $I^2$  (the magnetic intensity squared) and of  $S^2$  (the state of order squared). The variation of intensity with temperature gave a curve identical with that for the variation of order with temperature. In the magnetic studies it had been shown that in its initiation the loss of magnetic intensity was proportional to the  $1\frac{1}{2}$  power of the absolute temperature,<sup>1</sup> and he wondered whether Professor Bragg, during the course of his work, had studied the initiation of the order-disorder change at low temperatures, and whether the loss of order at low temperatures was also proportional to the  $1\frac{1}{2}$  power of the absolute temperature. If that could be examined (if it had not been examined already) and if it could be confirmed, it would throw further light on the exchange forces which were responsible for the changes in both those phenomena.

Dr. C. H. DESCH, F.R.S. (Vice-President, London), asked leave to say a few words from the standpoint of the old-fashioned metallurgist. He did not think that the scientific value of the authors' wonderful work could possibly be overrated, but he would like to comment on the X-ray technique. While Professor Bragg

<sup>1</sup> That was,  $I = I_0(1 - C \cdot T)$ , where  $C$  was a constant.



and Dr. Bradley were working at the National Physical Laboratory he had had an opportunity of seeing their work at first hand, and he thought it should be emphasised that the X-ray technique which was being used by them was far in advance of that which was being used anywhere else in the world. The pictures which were reproduced in the paper gave no idea of the beauty of the original films which Dr. Bradley prepared, and especially of those in the large camera with their great richness of lines when a complex structure was being dealt with. It was largely to the improvements in the technique, together with the wonderful theoretical grasp of Professor Bragg and his collaborators, that the great advance which had been made was due.

On the question of free-energy curves and surfaces, he hoped that at some time Professor Bragg would be able to write an essay on that subject which would make it clear to those working by the older methods. It was easy to understand the love of the physicist for this free-energy method of expression, because it satisfied the logical and tidy mind of the physicist; but could any practical use be made of it? At present the free-energy curves had to be deduced from the phase diagram, and all that was being done outside of that, apparently, was to decide from the possible free-energy curves and surfaces which might exist what phase arrangements were possible and what were not. No one ever made a scientific discovery by using the syllogisms of logic, but placing statements in the form of syllogisms might be a useful means of detecting fallacies. In the present case, he imagined that those who were using these free-energy concepts were using them to sort out possible and impossible phase arrangements. That, of course, was very useful in a complex system, but was there any prospect of being able to go further and obtain the free-energy curves from other data? It meant, of course, a very advanced state of knowledge of the interior of metals.

In the Introduction to the paper, Professor Bragg said: "Practically all metals and alloys used in industry have one or other of two simple crystalline patterns which are known as 'face-centred cubic' and 'body-centred cubic.'" In view of the fact that zinc and magnesium must be included in this category, it was necessary to include the hexagonal system as well. At the foot of the same page Professor Bragg said: "The microscope can only reveal structure which is on a scale larger than that of the wavelength of light. Even when pushed to the extreme limit, when magnifications of 2500 are attained, the details must be on a scale of  $10^{-4}$  cm. if they are to be seen." Was the limitation in fact quite so strict? It was so far as the resolution of a structure such as pearlite was concerned, but the resolving power of the microscope was based on the separation of two parallel lines, and, as the late Lord Rayleigh showed, it was possible to see an isolated particle which was much smaller than that, and as a matter of fact in some



of the photographs of precipitated carbides taken by Lucas with his fine technique it was possible to go one power of 10 further down, to  $10^{-5}$  cm., and actually see precipitated particles. There was still room, therefore, for a good deal of work to be done by the old methods. Dr. Hume-Rothery had referred to the necessary collaboration between the two. It must be remembered that the useful properties of alloys depended to a very large extent on the changes of concentration of the phases which took place with change of temperature, and it was difficult to see how the mapping of such diagrams as that could be done by X-rays; one must still use the thermal method, combined, perhaps, with the study of the change of other physical properties with temperature, and until the X-ray method for high temperatures had been very much more perfected, he thought that those diagrams must be worked out by the old method. He knew that Professor Bragg sympathised with the view that the advances to be made in future must be made by collaboration between the old and the new methods.

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#### CORRESPONDENCE.

Dr. T. SWINDEN (Member of Council, Stocksbridge, near Sheffield) wrote that this paper was of outstanding importance for several reasons. It was a scientific paper of high order, stating, with the lucidity for which Professor Bragg was famous, the principles of the work upon which he and his collaborators were engaged, together with some intimate details of the achievements of the investigations by this school of research. Apart from the intrinsic value of the work itself, it was intended to provide for the Members a broad insight into the type of work which the Research Council was encouraging, and it gave an opportunity for Members to express their commendation of the action taken by their representatives on the Research Council to assist in financing this work. In the view of those who had had the opportunity of following at fairly close quarters the evolution of this new school of metallurgy, it was in the best interests of the industry that every assistance possible should be given to it in its attempts to provide a rational and fundamental understanding of the constitution of metals and alloys.

It might usefully be emphasised that this was a British project, and, at a time when British prestige was being tested in so many directions, they would be lacking in a sense of duty if they did not ensure that this research had every possible support.

In the writer's laboratory, through the services of Dr. Jay, continuous use had been made of the X-ray study of crystal structure over the past three years, and it could be said without hesitation that, quite apart from the academic interest in providing a better fundamental understanding (which always had potential practical value), they had derived results of immediate practical importance

on many occasions. This applied particularly in their case to a study of refractory materials.

Dr. H. O'NEILL (Derby) wrote that Fig. 11 illustrated perhaps one of the most suggestive aspects of the X-ray work, and it would be of great value to industry if eventually some rules could be drawn up which would enable one to work out on paper just what the addition of one or two percent. of a strange element would do to an alloy. Sometimes supplies of raw material or of scrap of unusual composition became available for making engineering alloys, and the question at once arose as to whether they would be suitable for use. Ternary diagrams were not always known, and perhaps in any case more than three component elements were involved. For some ternary systems, what metallographers had called ternary coefficients of equivalence were available and enabled one to calculate what the microstructure of a new alloy should be. Perhaps it would not be impossible for the physicists to provide one eventually with ways of using electronic data so that one could calculate the microstructural group of an alloy containing a large number of components.

The authors would probably be themselves the last to suggest that metallurgists should cease to apply older methods to present problems. It was surprising what could be done by the old methods. Considering Fig. 36, for example, very refined specific-heat determinations had been compared with Brinell hardness measurements to show that age-hardening precipitation had occurred. He (Dr. O'Neill) had shown<sup>1</sup> that precipitation in this silver-copper system could be studied by refined hardness-testing methods so as to yield indicating factors typical of true precipitation. By applying the same factors to similar studies of duralumin it was shown<sup>2</sup> that the age-hardening at room temperature of this alloy was not a true precipitation process. This result was confirmed by X-ray diffraction tests, which in this case proved a somewhat less laborious method.

Dr. S. A. MAIN (Sheffield) wrote that he had been much interested to learn from Professor Bragg's spoken remarks of the success obtained in determining the structure of cementite. He hoped that Dr. Lipson would be encouraged to go on and examine the mysteries of martensite. He recognised the difficulties, but was led to make the suggestion by Professor Bragg's interesting explanation of the insight which had been obtained into the marshalling of solute atoms into a certain pattern, associated with special hardness and lack of plasticity. He understood that such arrangement of the atoms fell short of actual precipitation of the solute. If such was the case in martensite, it would do much to explain how the

<sup>1</sup> *Journal of the Institute of Metals*, 1933, vol. 52, p. 75.

<sup>2</sup> *Philosophical Magazine*, 1933, vol. 16, p. 913.

sequence from austenite, a complete solution, into martensite, and then into the definitely broken-up solution composed of ferrite + cementite, came about. That would settle an old-standing and very important question. Apart from fixing at long last the true nature of hardened steel, it would, as he himself had tried to show,<sup>1</sup> go far to resolve existing and purely theoretical ideas concerning what was known as precipitation-hardening.

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### AUTHORS' REPLY.

Professor W. L. BRAGG, F.R.S., in reply, said that with 90% of Dr. Hume-Rothery's remarks he was in complete agreement, and especially with what had been said about the need for collaboration. On some points Dr. Hume-Rothery was critical of the results, but his remarks were just the sort of criticism that the authors welcomed. He believed that they could reply to many of the objections raised, but he would not attempt to answer in detail at the moment. The uncertainties were not quite so bad as Dr. Hume-Rothery suggested, but he had laid his finger on some of the weaknesses of the method, weaknesses which the authors had condoned to themselves because they tried to make a wide and rapid survey. Personally, he thought that the point that the diagrams were constitutional diagrams rather than equilibrium diagrams was a fair one, and the authors would admit it, with a slight feeling on their part that they were really a little better than that.

Dr. McCance had raised a point relating to the initiation of the order-disorder phenomenon at low temperatures, when it was just starting. It was impossible to establish the equilibrium state of order at such temperatures, because everything was so sluggish, but theory indicated that it was not a  $1\frac{1}{2}$ -power law of the absolute temperature. The loss of order began very much more gradually than that. He would like, however, to go into that point more closely with Dr. McCance.

He agreed absolutely with Dr. Desch that more collaboration was required. He and his collaborators were not experts in the older metallurgical methods, and often felt that they were fools rushing in where angels feared to tread. On the other hand, fools were sometimes useful; they rushed into certain places and found out that these were not so hard to enter as had been thought. If in setting the limit to the microscope his approximate estimate of  $10^{-4}$  was too coarse, he was perfectly willing to extend it. He would like to make it clear, however, that his estimate referred to the resolution of near objects or fine structure, not to the smallest object which could be seen.

In conclusion, he wished to express his warm thanks to those who had taken part in the discussion at the meeting and by corre-

<sup>1</sup> *Metal Treatment*, 1938-39, vol. 4, Winter Issue, p. 158.

spondence. To him, one of the most satisfactory features of the group of researches which he had surveyed in this paper had been the contacts which it had brought with industry. He would like to think that the authors' work had been of value to industry, but realised that in long-range research of this kind one could not hope for immediate results. He felt that the best contribution that they could make on their side was to try to summarise certain fundamental principles which governed the behaviour of alloys, in the hope that this would create a point of view which would enable the industrialist, with his unrivalled technical knowledge, to gain more insight into the reasons for the success or failure of methods that he employed, and to suggest new possibilities. On the other side, there could be no question of the assistance which industry had given the authors, the effect of which had been immediate. The problems that they had been asked to consider had suggested new lines of research, and had directed the thoughts of many investigators in Great Britain to the problems of the physics of metals.

Dr. A. J. BRADLEY, F.R.S., in reply to Dr. Hume-Rothery, said he would state quite frankly what the authors felt to be their contribution towards co-operation with workers using older methods for the investigation of phase diagrams. At the outset he would like to make it clear that the accurate determination of phase equilibrium diagrams had not been their object. This type of work could, of course, be done by X-ray methods, but the microscope appeared to be at least as satisfactory in the majority of cases when extreme accuracy was aimed at. There were, however, examples when one or other method had a decided advantage. It was then for the individual investigator to decide for himself which method might most readily be used.

The authors' present object was to point out what could be done by X-ray methods in breaking entirely new ground. The exploratory information so obtained must certainly be supplemented later by the older methods. Thermal analysis was, of course, essential for fixing the positions of the solidus and liquidus, and microscopic examination must be employed while investigating the solidus, especially in the study of eutectics, about which X-rays said practically nothing. X-ray photography could never replace the older methods in these fields. Thus, in general the ternary diagrams of low-melting alloys would conveniently be completely explored without the use of X-rays. For similar reasons the high-temperature investigation of ferrous alloys, say, from  $1000^{\circ}\text{C.}$  upwards, was best left to the older methods.

It was at temperatures well below the melting point that X-ray methods were most valuable. The diagrams given by the authors represented the state of affairs (he deliberately refrained from saying state of equilibrium) at the lowest possible temperatures consistent with reasonable times of heat treatment. As Dr. Hume-Rothery



pointed out, these temperatures were not uniform throughout the systems under consideration, and the next step in the work was to determine true equilibrium conditions by quenching from successively higher temperatures. These results would ultimately overlap those obtained by other workers who had approached the diagrams from the upper temperature limit, starting from the solidus and liquidus curves.

While thoroughly agreeing with Dr. Hume-Rothery's comments on the necessity for the analysis of filings in cases where high accuracy was required, the authors felt that this should not be allowed to slow up the preliminary attack on the phase diagram as a whole. Though in the case of binary systems it might be possible to start from one end of the diagram and carry out the investigation piecemeal, preserving the highest accuracy throughout, this might not be the case for ternary systems. There it might be necessary to obtain a general survey of the whole diagram in order to understand the reactions which were occurring in one corner of the system. These latter alone would require immediate accurate information, while for the remainder of the system the more general survey might for the time suffice.

The matter of the composition of filings was of great importance. Under no circumstances must one sieve filings from two-phase alloys. The relative proportions of the constituents were bound to be changed by this procedure. Even apart from this difficulty, it was necessary to observe the greatest care in making deductions from the relative proportions of the phases present in a two-phase alloy. For example, when a hard phase was present together with a soft one, the latter might yield a disproportionate amount of filings. The true position of the phase boundary was therefore to be deduced only from alloys near the phase boundaries and not from those in the middle of the two-phase fields.

The tie-lines had been determined only approximately and much more work was required here. Their directions usually changed for different temperatures, so that they must ultimately be determined accurately for each quenching temperature. For this purpose the lattice spacing contours were first fixed for each of the neighbouring solid solutions. Their linear continuations in the two-phase region were tie-lines. One therefore drew a straight line through each of the points in a two-phase region to the appropriate contour in one of the single-phase regions. These straight lines were the tie-lines. It was only necessary to know the spacing contours of one of the neighbouring phases. An insuperable difficulty arose if the spacing contours followed both the phase boundaries. Such a predicament was not impossible; the authors had, in fact, found examples of it.

Dr. C. SYKES thanked the various contributors who had made kind references to his part of the paper. Their comments, however, he thought needed no detailed reply.



# THE DAMPING CAPACITY OF STEEL AND ITS MEASUREMENT.\*

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(Figs. 42 to 45 = Plates V. and VI.)

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## SUMMARY.

The Föppl-Pertz apparatus for the measurement of "damping capacity" was found to yield unduly high values, mainly as the result of frictional losses between the stylus and the recording medium. To eliminate these, the instrument was modified so as to employ an optical recording device. Particular attention has been paid to a consideration of the effect on damping capacity of factors such as the initial stress, bending, size and shape of the specimen, &c. An account is given of experiments to study the influence of moderate temperatures on the damping capacity of a series of typical steels.

This work, which is of an exploratory nature, covers only an account of the experimental results and no attempt is made to deal with them theoretically.

## INTRODUCTION.

In recent years a considerable amount of work has been published on the subject of "internal friction" or "mechanical hysteresis," to which, in many current publications, the term "damping capacity" is applied. Amongst the earliest workers in this field were Hopkinson and Williams<sup>(13)</sup> and Rowett,<sup>(14)</sup> whilst reference may also be made to later work by Brophy,<sup>(1, 2)</sup> Canfield,<sup>(3, 4)</sup> Peterson and Moore,<sup>(5)</sup> Dorey,<sup>(6)</sup> Bacon,<sup>(7)</sup> Inglis,<sup>(8, 9)</sup> Shannon<sup>(10)</sup> and many others.

In 1911 Robin<sup>(24)</sup> published an account of work on the influence of temperature upon the acoustical properties of steel. By determining the time for which the sound produced by striking a bar of the material a standard blow could be heard, curves were obtained which showed marked abnormalities. At a temperature of 120° C., in particular, soft iron refused to ring, a state of affairs which Robin termed "aphonia."

Since the decay of the sound would appear to be closely analogous to the damping of a mechanical vibration, it appeared reasonable to suppose that measurements of "damping capacity" as a function

\* Received February 15, 1940.

of temperature might well be employed to investigate the "low-temperature abnormalities" of steel. The present work was, therefore, undertaken to examine the influence of moderate temperatures on the damping capacity of some typical steels of different heat-treatments and chemical composition.

It has been shown, however, that damping capacity is a property of a super-sensitive nature, and unless the test-pieces are produced from materials almost ideally identical with regard to the previous history and source of supply, the results may vary greatly, even when the ordinary composition is much the same. There are, further, several potential sources of error in the apparatus, and it appeared essential to examine these in detail before proceeding to the real subject of the research. The first part of this paper deals, therefore, with the actual measurement of damping capacity in a machine of the Föppl-Pertz type. It is evident that the results are of real significance if, and only if, the energy losses in the apparatus can be reduced to a point where they are small in comparison with those in the specimen itself. With the machine as finally devised, a series of observations on two specimens of identical material machined under carefully standardised conditions have given results which vary by only 1-3%. It would appear, therefore, that the basic features of the apparatus employed for this work are sound, and there is evidence to suggest that the results obtained do bear some close relationship to the real damping capacity of the material. It may be pointed out, however, that there is one source of error which has not been eliminated, namely, that due to the air-resistance of the vibrating parts. We have no means of estimating the magnitude of this, though it cannot introduce an error into the results which exceeds at the very most 0.4%, the lowest value of damping capacity which has been observed.

It is premature at the present time to draw conclusions in terms of any fundamental theory; the results are presented merely as a contribution to the study of a problem to the ultimate elucidation of which they may assist.

When a body is set in free vibration, and even after all external forces, *e.g.*, the resistance of the air, the frictional resistance of bearings, &c., have been eliminated, there is still a continuous decrease of amplitude with time, the system ultimately reaching a state of rest. Briefly, "damping capacity" is that property of the material which causes these vibrations to disappear. Although the general idea is far from new, the term "damping"—as applied to metals in torsion—appears to have been first introduced by Föppl<sup>(12)</sup> in 1923, who defined it as "the amount of work dissipated as heat by a unit volume of a material during a complete reversed cycle of unit stress," and expressed it as the "specific damping capacity,"  $P$  %. Different investigators have, however, given various names to this property. Kimball,<sup>(15)</sup> for instance, calls it "internal friction" and measures it in terms of the logarithmic decrement

which can be shown to be  $P/2$ . Other terms employed are "crackless plasticity" and "mechanical hysteresis loss."<sup>(10)</sup> In the present paper the term "specific damping capacity," denoted by  $P$ , is used.

When a material is subjected to a cycle of stress below the "elastic limit," it is now generally appreciated that a hysteresis loop is obtained. The damping of the material may also be defined as the energy dissipated per unit volume, per cycle, *i.e.*, by the area of this loop. If the material were perfectly elastic between the limits of stress employed, there would clearly be no loop and the damping capacity would be zero.

#### METHODS OF EXPRESSING DAMPING CAPACITY.

Of the various methods of measuring the damping capacity so far employed, a summary of which has been given by Föppl, the one used in the present work was the determination of the logarithmic decrement, *i.e.*, the natural logarithm of the ratio of any two successive amplitudes of a vibration the amplitude of which decreases exponentially. Thus for any amplitude  $y$ , the logarithmic decrement is:

$$\delta = \log_e \left( \frac{y + \Delta y}{y} \right) \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

where  $\Delta y$  represents the decrease of  $y$  per cycle.

But

$$\log_e \left( \frac{y + \Delta y}{y} \right) = \frac{y + \Delta y}{y} - 1 - \frac{1}{2} \left[ \frac{y + \Delta y}{y} - 1 \right]^2 + \dots,$$

whence

$$\delta = \frac{y + \Delta y - y}{y} - \frac{1}{2} \left[ \frac{y + \Delta y}{y} - 1 \right]^2 + \dots$$

or, neglecting the terms of the second and higher orders,

$$\delta = \frac{\Delta y}{y} \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

The "specific damping capacity," on the other hand, is the ratio of the loss of energy per cycle to the maximum energy of that cycle. Once  $\delta$  is known the amount of energy dissipated per cycle,  $\Delta w$ , can be calculated<sup>(16)</sup> as follows: Since the energy required to twist the bar is proportional to the square of the amplitude, the total amount of vibrational energy,  $w$ , at some time  $T$  is  $ky^2$ . The total vibrational energy one cycle later is

$$w - \Delta w = k(y - \Delta y)^2 \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where  $\Delta w$  is the amount of energy dissipated, and  $\Delta y$  is the decrease of amplitude. Subtracting,

$$\Delta w = 2ky\Delta y \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

whence

$$P = \frac{\Delta w}{w} = \frac{2ky\Delta y}{ky^2} = 2 \frac{\Delta y}{y} = 2\delta \quad . \quad . \quad . \quad . \quad (5)$$

In other words, the ratio of the loss of energy per cycle to the maximum energy of that cycle, *i.e.*, the "specific damping capacity," is twice the logarithmic decrement. This relationship is only correct to a first approximation, due in part to the fact that recent researches have shown that the amplitude does not always decay exponentially with time.<sup>(20)</sup> This conclusion has been confirmed by the present work. It has not been found possible to express the whole—or even any very appreciable portion—of the damping curve by any simple mathematical equation, the damping properties appearing to vary somewhat as the maximum surface stress decreases. To what extent this is an inherent property of the material, or, on the other hand, is the result of extraneous losses of energy in the apparatus, or due to the resistance of the air we have no means of determining.

As early as 1912 Hopkinson and Williams<sup>(13)</sup> showed that there might be some decrease of hysteresis at high speeds, of the order of 7200 cycles per min., as compared with that at very low ones, but that the difference could not be more than 30%. In 1914, Rowett<sup>(14)</sup> published the results of experiments on thin-walled tubes in torsion, and found that the energy dissipated per cycle is probably the same to within 5% at both high and low speeds. The effect of the frequency of the stress cycle has also been studied by Föppl,<sup>(17, 18)</sup> Becker<sup>(19)</sup> and others,<sup>(15, 20)</sup> who have arrived at the same conclusion as Rowett, namely, that the width of the hysteresis loop, or the damping capacity, is independent of the rate of strain or frequency. Other tests carried out to determine whether there is any change in damping capacity with variations of frequency, will be referred to in the following pages.

#### APPARATUS.

Of the methods available for the measurement of damping capacity, the free-vibration method appeared to be especially suited to the present investigation. The rapidity with which the test is carried out renders it particularly valuable in the case of materials the properties of which change during test—provided, of course, that the change is not also rapid and due to the test itself. Exact temperature control of the specimen is possible over a wide range, whilst means are available for the variation and accurate adjustment of the amount of stress to which the specimen is initially subjected. The apparatus employed was constructed on the general lines of the Föppl-Pertz machine.<sup>(11)</sup> Briefly, it consists, Figs. 1 and 42, of a rectangular steel frame *A* very rigidly bolted together at the angles. The specimen, Fig. 1, is firmly clamped to this at its lower end by the grip *G2*, its upper end being clamped equally

rigidly to the swing-bar *B* ( $23 \times 1 \times 2$  in.) by the grip *G1*. By means of the electro-magnets, *M1* and *M2*, which hold the ends of the swing-bar against the rotatable feet *F*, *F*, a predetermined strain can, within limits, be applied to the specimen prior to test.

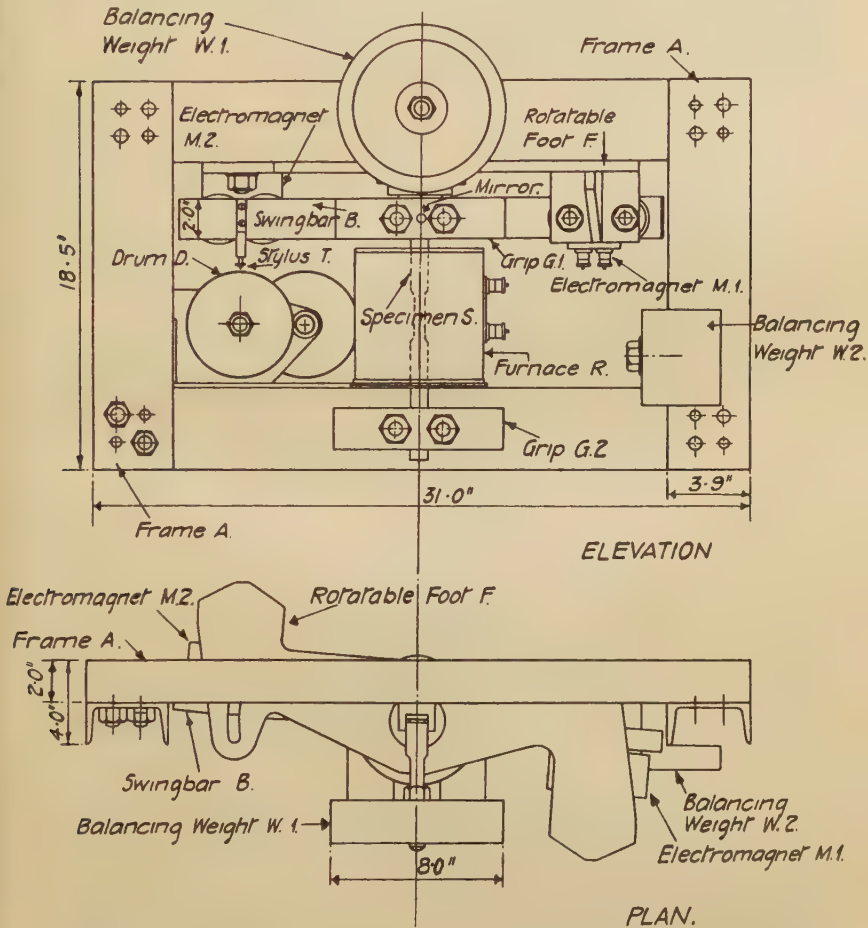


FIG. 1.—The Apparatus.

On breaking the magnetising current the swing-bar and specimen at once pass into smooth oscillation.

Attached to the swing-bar in the earlier tests was a stylus, *T*, which recorded the diminishing vibrations on smoked or waxed paper attached to the clockwork-driven drum, *D*. The speed of



this being known, the amplitude, frequency and rate of decay of the oscillations can at once be determined from the record.

Apart from an optical recording system to be mentioned later, probably the most important modification of Föppl's apparatus was in connection with the pivot supporting the swing-bar and the upper end of the specimen, for which a self-aligning journal was substituted. It was thus hoped, on the one hand, to reduce the

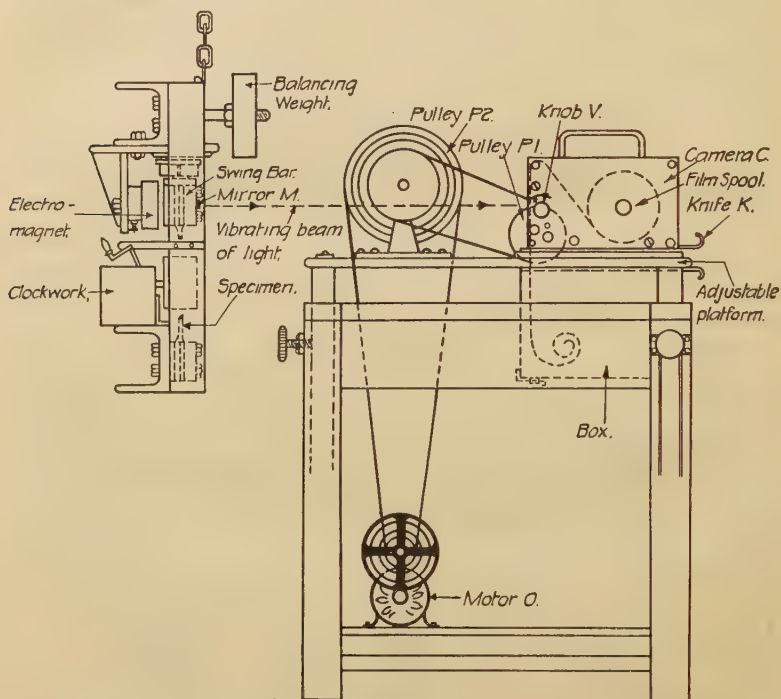


FIG. 2.—Sectional Diagram Illustrating the Arrangement of the Recording Camera and the Föppl-Pertz Apparatus.

bearing friction to a minimum, and, on the other hand, to make allowance for any slight eccentricity of the specimen.

Specimens which are not quite straight tend to give unduly high damping values. By the introduction of this self-aligning journal, errors due to slight bending in the specimen are to a large extent eliminated, the swing-bar taking up a position such that the axis of the specimen still passes through the central line of the journal.

Another and very serious source of error was occasioned by the recording system. As will be shown later, the stylus swinging

across the revolving strip of paper introduced such a large frictional loss that this method of registration had to be discarded, an optical recording system being substituted. This was effected by attaching a small mirror to the swing bar, a beam of light reflected from which recorded the vibrational oscillations of the bar on a photographic film. The whole arrangement is shown in Fig. 2. Briefly, the film is moved by a small pulley *P1* (in the camera *C*), which is driven by the motor *O* through a bigger pulley *P2*. A beam of light is thrown on to the mirror *M*, is reflected, and then falls on the sensitive film through a small slit in the camera. The shutter is operated by the knob *V*. The exposed film runs down into a light-tight box placed under the adjustable platform, and can be cut at any desired length by the knife *K*. A typical record is given in Fig. 45.

In experiments at temperatures above the normal, an electric furnace was placed around the specimen, as is shown in Figs. 1 and

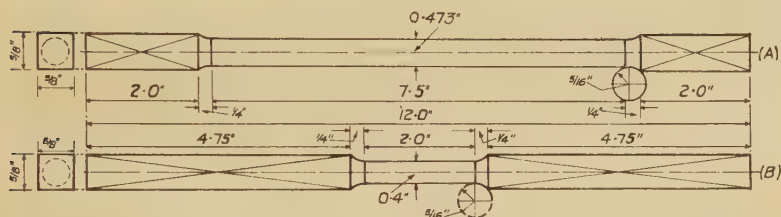


FIG. 3.—Dimensions of the Test-Pieces.

42, great care being taken that there should be no contact between the furnace and the test-piece. Furnace openings were closed by thin sheets of asbestos in such a way as to introduce no frictional losses.

Fig. 3, (A) and (B), shows the shapes and dimensions of the test-pieces employed, the latter, short form, being employed in all high-temperature tests.

The static calibration of the specimen was carried out on the same apparatus. The angle of twist produced by a given torque was measured by a reflected beam of light falling on a scale attached to the camera. The principle is the same as that underlying the torsion-strain meter.<sup>(22)</sup> Knowing the distance, *d*, between the camera and the mirror, the gauge length, *l*, radius, *r*, and modulus of rigidity, *C*, of the specimen, the maximum fibre stress, *q*, can be calculated from the equation :

$$q = \frac{Cr}{l} \cdot \theta,$$

where  $\theta$  is the angle of twist in radians, *i.e.*, half the deflection of the beam of light.

Since the effective length of the furnace was three times the gauge length of the test-piece, a very uniform distribution of temperature was maintained in the higher-temperature work. Up to  $310^{\circ}$  C., the highest temperature normally employed, the maximum variation over the gauge length of the specimen was not more than  $\pm 2^{\circ}$  C. A copper-constantan thermocouple, very lightly attached to the central portion of the test-piece, was employed for measuring the temperature.

In order to eliminate the loss of energy to the supports, the whole apparatus was suspended by a thin chain, the upper end of which was attached to a ball-bearing system fixed to a rigid steel framework, standing on the wooden floor.

### FACTORS INFLUENCING DAMPING.

Before commencing actual measurements of the damping properties of steel, it appeared necessary to investigate at some length the factors which might affect such determinations. Among some of the more obvious of these were the initial stress to which the specimen was subjected before test, the method of recording the vibrations, the suspension of the apparatus, losses in the machine itself, the effect of the grips, distortion of the specimen, the machining and shape of the specimen, and overstrain. Each of these has been considered in some detail.

Although it is easy to envisage influences which will cause a loss of energy from the test-piece to the frame, &c., and hence yield unduly high values of the damping capacity, it does not appear to the authors possible to imagine any state of affairs in their tests such that energy is lost too slowly. They have, therefore, worked on the assumption, which appears to them to be justified, that though high results are to be expected if the technique of measurement is faulty, low ones can occur through carelessness alone. The lowest result of  $P$  for any given set of experimental conditions has, therefore, been accepted as representing most closely the true value. From this point of view, they believe that their apparatus and technique have given results which are as reliable as any yet recorded, and, as will be seen later, values of  $P$  down to 0.4% have been repeatedly obtained.

#### *Initial Stress.*

As is shown in Fig. 4, the initial stress ( $I.S.$ ) to which the specimen is subjected may very greatly affect the value of the damping capacity, this, for a given torsional fibre stress, being higher for a low initial stress than for a higher one. For an initial stress of 11,736 lb. per sq. in., for example, the damping capacity at a stress of 8000 lb. per sq. in. is no less than 63% higher than that at the same fibre stress for an initial stress of 32,600 lb. per sq. in. It is also evident that for high initial stresses the damping capacity tends

to attain a constant value. There is some indication that at low stresses the damping also approaches a uniform value irrespective of the initial stress. These results were obtained on the short specimens (Fig. 3, type *B*). Tests, on the other hand, carried out on the same material but using the specimen with a longer gauge

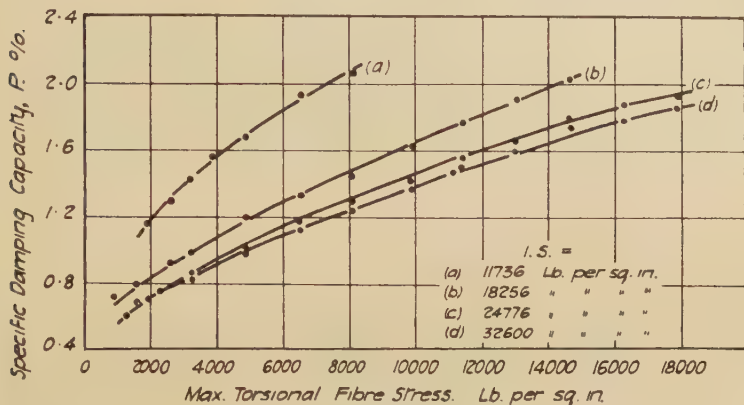


FIG. 4.—0.4% Carbon Steel, cold-rolled, optically recorded. "Short" specimen (*B*).

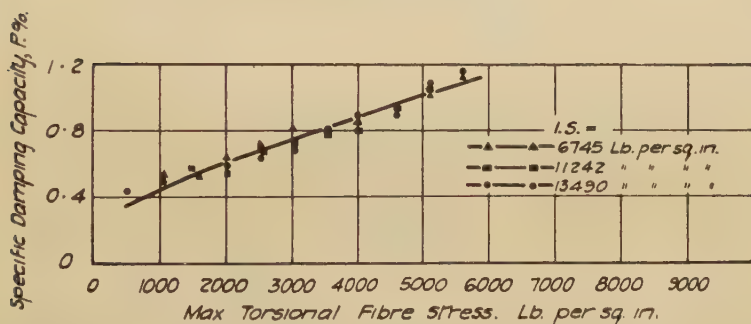


FIG. 5.—0.4% Carbon Steel, cold-rolled, optically recorded. "Long" specimen (*A*).

length (Fig. 3, type *A*), gave the same damping capacities even under different values of initial stress. This is shown in Fig. 5.

The difference between the results recorded in Figs. 4 and 5 is surprising. That the cause lies in the initial stress on the short specimens having exceeded the elastic limit can hardly be the case when it is borne in mind, in the first place, that the maximum stress imposed—14.4 tons per sq. in.—is below the limit of proportionality of this material, and, in the second, that plastic deformation of the material, so far from lowering the damping, increases it considerably.

It may be pointed out here that the record itself shows clearly any permanent deformation of the specimen due to the imposition of stresses exceeding the elastic limit. The original datum line should coincide with that after the test, and, in fact, did do so in all except a very few cases, such, for instance, as the tests on Armco iron at the highest temperatures.

Similar experiments on the same material were also made with the Cambridge torsional recorder. The results, which are not quantitatively comparable with those of Figs. 4 and 5, since the records were obtained mechanically, are shown in Fig. 6. Just as is the case in Fig. 4, they show a marked fall of damping value with

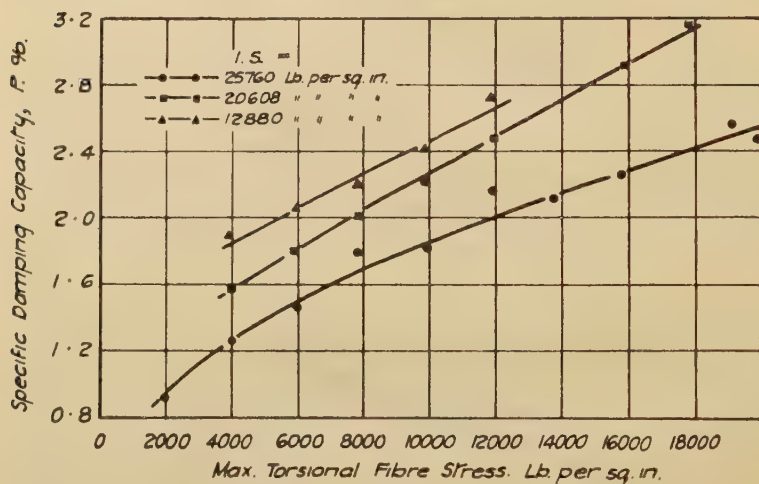


FIG. 6.—0.4% Carbon Steel, cold-rolled. Recording method, stylus-on-celluloid.

increase of initial stress. It is clear, therefore, that some fixed initial stress must be adopted, and in this work that of 19,560 lb. (8.7 tons) per sq. in. was arbitrarily adopted for all the tests on the short specimen, corresponding to an overall amplitude of 6 cm. on the record.

It was observed at an early stage of the work that the damping values obtained for the first test of the specimen were in general slightly higher than those for the second, and that after a few preliminary runs the curves became very nearly identical. This is shown in Fig. 7. On this account the results recorded here were, unless otherwise stated, those for the fourth "run" of the specimen. This discrepancy was not, however, observed in all cases, in many instances the curves for all the four "runs" being identical.



### Method of Recording.

Any kind of mechanical recording method was found to involve astonishingly high energy losses due to the friction between the stylus and the recording medium, *i.e.*, unduly high values of  $P$ . Curves obtained from the records made mechanically on smoked paper, waxed paper and celluloid are given in Fig. 8. The curve obtained optically, in which such frictional loss is necessarily absent, is added for comparison. The specific damping capacity at low stresses is raised, in the case of the record taken on smoked paper, to about five times the value obtained optically. At a stress of about 5000 lb. per sq. in., for instance, the smoked paper value of  $P$  is around 4.7 as compared with about 0.9 from the optical record.

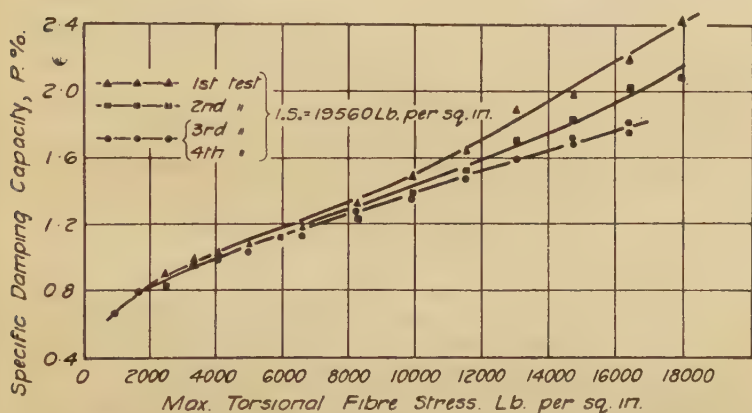


FIG. 7.—0.9% Carbon Steel, hot-rolled, optically recorded.

Almost all of the results so far published show unduly high values for the damping capacities, due to the fact that mechanical means of recording were employed.

### Suspension.

The reason for suspending the whole unit is to prevent energy being transmitted to the support. If an optical recording system is employed, it is necessary that the whole apparatus should be as motionless as possible, since otherwise its movements are superimposed on the torsional vibrations of the swing-bar. A typical record is shown in Fig. 45, where a small movement in the vertical plane of the apparatus as a whole is clearly to be discerned. Small oscillations such as these of Fig. 45, however, result in no appreciable error in the value of  $P$  as determined.

Tests with the apparatus placed on a wooden table gave

exceedingly high damping values, Fig. 9 (a).<sup>\*</sup> Even the general shape of the curve is different from that of curve 9 (b), taken when the

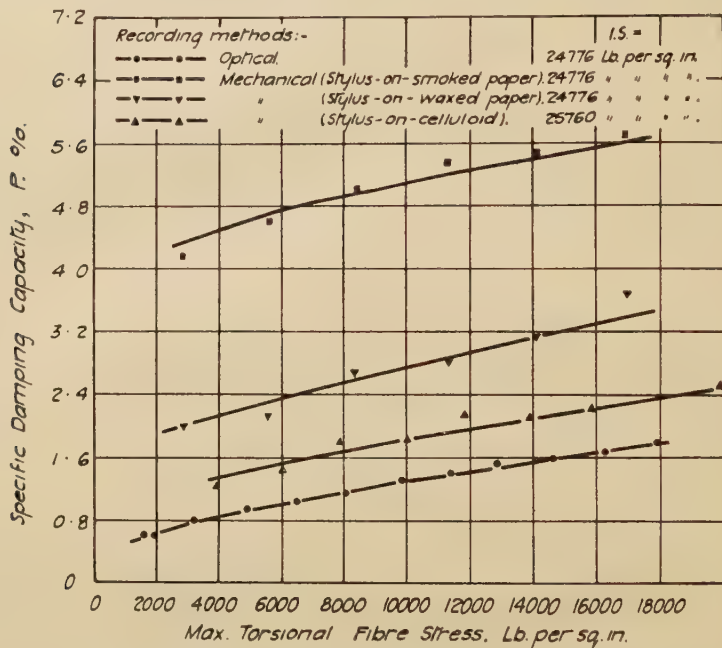


FIG. 8.—0.4% Carbon Steel, cold-rolled.

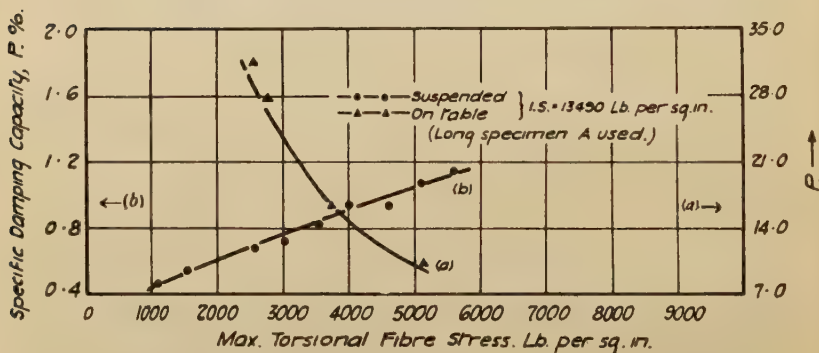


FIG. 9.—0.4% Carbon Steel, cold-rolled, optically recorded.

apparatus was suspended. The damping in the case of (a) rises rapidly as the torsional stress decreases, instead of falling as is

<sup>\*</sup> It should be pointed out that in Fig. 9 the scale (on the right) for curve (a) is very different from that on the left for curve (b).

normally the case. This is, perhaps, to be expected, since the energy losses due to friction between the table and the apparatus may be expected to be relatively the greater at smaller amplitudes of stress. Thus the specific damping capacity at 5000 lb. per sq. in. is some 10 times as great when the apparatus is placed on a table, as it is when suspended, the corresponding figure rising to nearly 40 times at a stress of 2700 lb. per sq. in. It is clear that if the apparatus is to be fastened down on its bed, a procedure sometimes adopted, this must be done very rigidly if no losses due to friction are to arise. Even then there is, as yet, no ground for the belief that the results are any more reliable than those obtained with the method of suspension which the authors have employed.

### *Instrument Losses.*

Regarding the energy losses in the apparatus, no method is at present available by which these could be quantitatively determined,

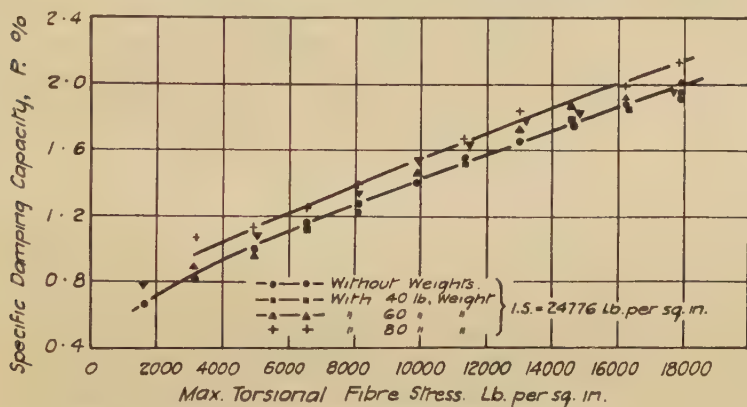


FIG. 10.—0.4% Carbon Steel, cold-rolled, optically recorded.

though clearly such losses in the frame can be reduced by making the latter very heavy and rigid. In the circumstances all that appeared to be possible was to determine the probable magnitude of the error due to this cause by empirical means. Damping capacities were, therefore, determined in one case after removing the heavy balancing weights  $W_1$  and  $W_2$  (Fig. 1) from the frame and alternatively by putting on extra weights over and above these. The extra weights—of 40, 60 and 80 lb.—must be very rigidly fastened to the frame or loss of energy results, due apparently to the friction between them and the frame. Above 80 lb. it was found difficult to attach these extra weights with sufficient rigidity. Tests were made by placing the weights both symmetrically and asymmetrically over the upper span of the instrument frame.

A slight rise in damping in the case of 60- and 80-lb. weights is noticeable, but this may possibly be due to the slackness which tends to develop between the weights and the frame during the preparatory runs. As Fig. 10 shows, the difference between the values of  $\bar{P}$  obtained without the balance weights, and those with both these and an extra 40 to 60 lb., is quite small, whence the conclusion is drawn that errors due to losses in the frame are at any rate not high.

### Grips.

It was found that loose clamping of the specimen was highly detrimental. Any slipping, however slight, between the specimen

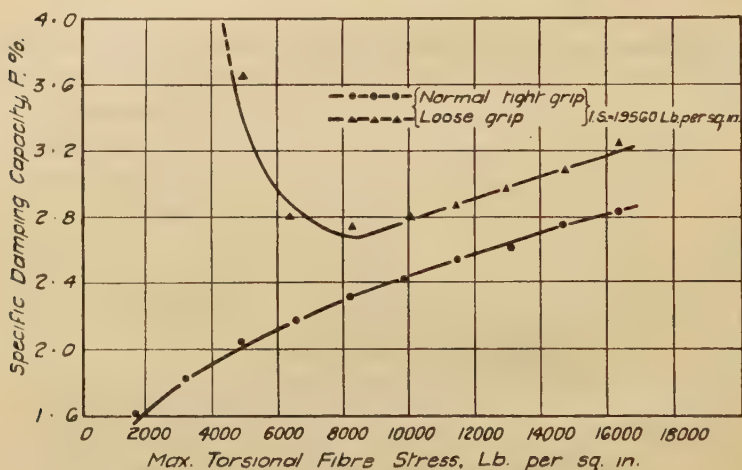


FIG. 11.—0.2% Carbon Steel, hot-rolled, optically recorded.

and the grips results in a loss of energy and a rise in the apparent damping value. This is especially the case for low values of stress, and is shown in Fig. 11. After testing with the loose grips, the grips were firmly tightened up and the specimen was re-tested. Damping then fell to the original values of the normal curve.

### Bending of Specimen.

Unless great care was taken during machining, it was not always easy, especially in the case of the long ones, to obtain specimens which were absolutely free from slight bending. To determine the effect of such bending on the results, thin metal packing pieces 0.007 in., 0.014 in. and 0.021 in. thick were inserted between the specimen and grips, and tests carried out both on the machine described here and on the standard Cambridge apparatus. As will

be seen from Fig. 12A, the results in the authors' machine were unaffected, even with the thickest packing pieces, due presumably to the design of the self-aligning journal system. In the latter apparatus, however, Fig. 12B, the results of the tests with packing pieces showed a marked increase in the damping values.

Although it has been shown that with the authors' apparatus slight degrees of bending are without sensible influence on the

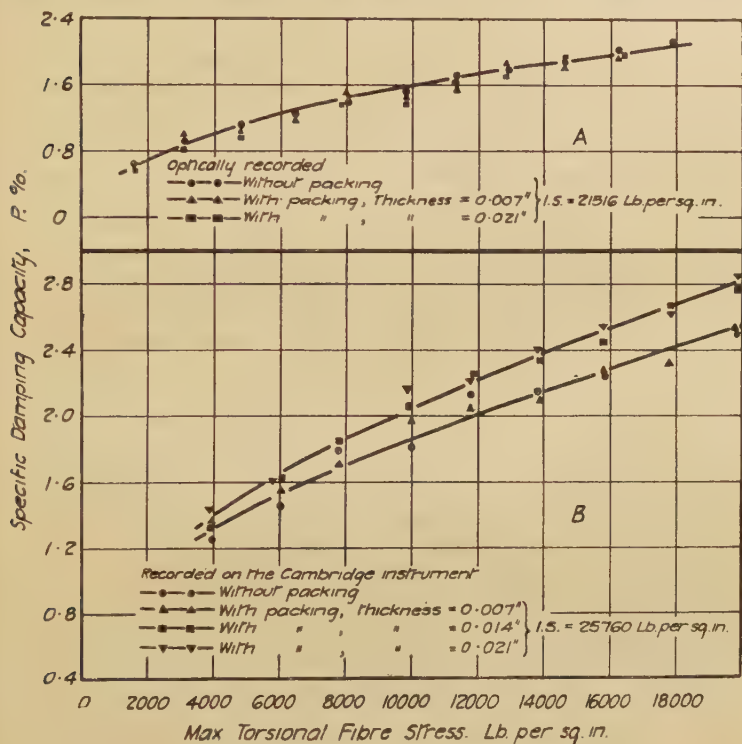


FIG. 12.—0.4% Carbon Steel, cold-rolled.

results obtained, deliberately bent test-pieces with a much greater deformation do, as will be seen from Fig. 13, lead to high results. It follows that care must still be taken in producing the specimens, but that the slight distortions due, for instance, to the relief of slight internal stresses during machining, do give standard results with the form of construction which has been employed. From these results, it would appear that the damping capacity of specimens in combined bending and torsion is higher than would be found for torsion alone, though it is possible that part of the difference is due



to the cold-work done on the steel during the bending, plastic deformation tending to increase damping values.

### Shape of the Specimen.

According to Föppl<sup>(11)</sup> and Von Heydekampf,<sup>(21)</sup> the damping capacity of a given material is a physical property of the material,

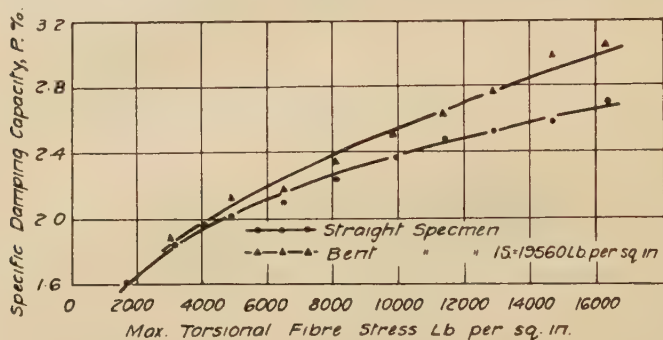


FIG. 13.—0.2% Carbon Steel, hot-rolled, optically recorded.

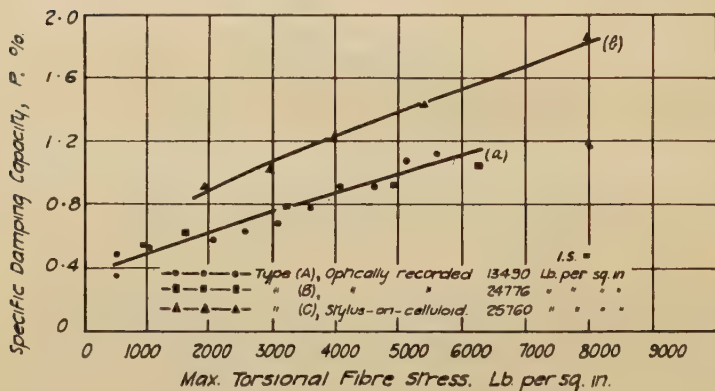


FIG. 14.—0.4% Carbon Steel, cold-rolled.

which is independent of the size or shape of specimen. To examine this point, tests were carried out on the 0.4% carbon steel, using specimens of both types A and B, Fig. 3. Apart from the shape of the specimen the experimental conditions were maintained as constant as possible in each set of tests, and, as will be seen, the results fit well on a single curve (a) of Fig. 14.

These tests are incidentally of interest in another connection. It will be noted in many of the figures that the curves fall off

markedly at very low stress. The question, therefore, arose as to whether at zero stress there was still any damping effect. Since the difficulties of measuring the records become very great at very low stresses, no perfectly dogmatic answer can as yet be given. From Fig. 14 it is, however, quite clear that at a stress of only 500 lb. per sq. in.,  $P$  has a definite value. As confirmation of this, measurements were made down to as low a figure as 200 lb. per sq. in. in one or two cases where the records were especially clear, and with the same result. None of these results is inconsistent with the view that steel has a definite damping capacity even at zero stress. If this be true, it follows that a looped curve of mechanical hysteresis is always to be expected.

To determine whether improper "shouldering" of the specimen has any effect on the value of the damping capacity, a specimen was prepared with sharp shoulders; curves for this specimen and for

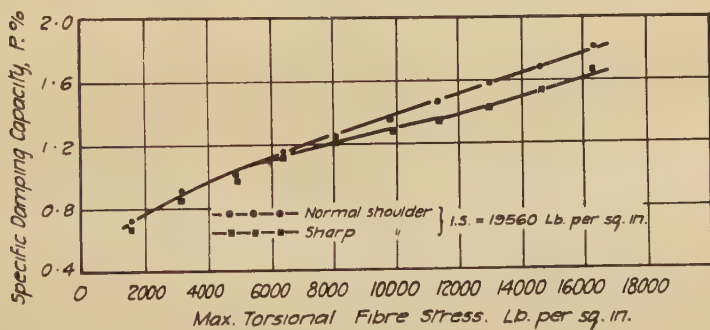


FIG. 15.—0.9% Carbon Steel, hot-rolled, optically recorded.

one with the normal shoulder are given in Fig. 15. The square shoulders appear slightly to decrease the damping at higher stresses, though the results at, and below, a stress of 6000 lb. per sq. in. are the same. Uniform shouldering of all specimens is, therefore, important.

### Frequency.

Experiments were carried out on specimens of the normal gauge lengths but of 0.4 and 0.303 in. dia. respectively. This brought about a change in the frequency of vibration, but, as will be seen from Fig. 16, there is no appreciable difference in the damping values within the range of frequencies investigated, *i.e.*, from 792 to 453 cycles per min.

### Overstraining.

A few tests to study the effect of overstraining were made on the Cambridge instrument, the material used being the medium-carbon

steel in the cold-rolled condition. The results of these experiments are shown in Fig. 17. Curve (a) represents damping values for an initial stress of 11 tons per sq. in., *i.e.*, below the limit of proportion-

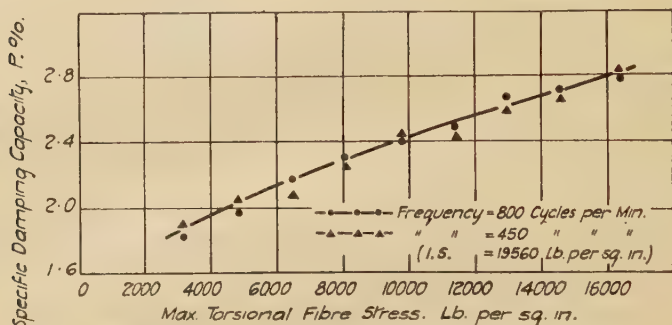


FIG. 16.—0.2% Carbon Steel, hot-rolled.

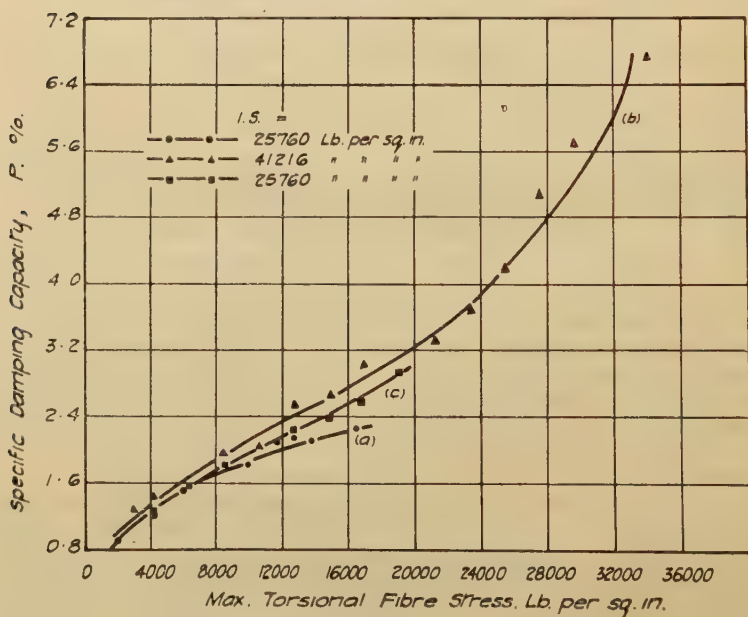


FIG. 17.—0.4% Carbon Steel, cold-rolled.

ality. In case (b) the specimen was overstrained by an initial stress of about 18 tons per sq. in. and at once tested. It may be pointed out here that in case (b) the initial and final datum lines of

the record did not coincide when the torsion bar had ceased to vibrate, owing to permanent plastic strain on the specimen—a valuable check upon the fact that the “elastic limit” had been exceeded. After the tests on the overstrained material, the specimen was again tested at a normal stress of 11.0 tons per sq. in., with the results shown in curve (c).

From these curves it will be seen that the damping capacity is distinctly higher for the plastically deformed steel. From the curve (c) it would appear that the subsequent subsection of the overstrained material to a series of vibrations of medium intensity reduces the damping capacity again, this ultimately returning to its original value, at any rate so far as the lower range of stress is concerned.

### EXPERIMENTAL TECHNIQUE.

The test-piece having been inserted in the machine and firmly clamped—in the case of the tests at elevated temperatures—the furnace was heated to, and maintained at the required temperature for one hour before taking the record. In most cases the tests were carried up to 290° C., a few being continued to 330° C. As has already been stated, the first three “runs” on the specimen were not taken into account, the fourth and subsequent runs only being recorded. The values embodied here are an average of two, three or more consistent results. Although any variation would not affect the results, the speed of the camera was maintained throughout. From the photographic records the logarithmic decrements were calculated. Since it is difficult, especially at low stresses, to measure accurately the change in amplitude for a single cycle, it was thought desirable to use twenty-one cycles as a basis for this calculation. The expression used was

$$\delta = \frac{\log_e A_1 - \log_e A_n}{(n - 1)}$$

where  $\delta$  is the logarithmic decrement,  $A_1$  the reading of the first overall amplitude, and  $A_n$  that of the  $n^{\text{th}}$ , *i.e.*, the twenty-first. The specific damping capacity, which, as has been shown, is twice the logarithmic decrement, is plotted against the corresponding maximum fibre stress in torsion. The procedure adopted was to take the records from room temperature upwards at intervals of 20° C. After finishing the last experiment, say at 290° C., the specimen was allowed to cool overnight in the furnace, without being removed from the machine, and retested. In many cases this was repeated for a third and even fourth time to see if changes in the values of  $P$  had occurred. As has already been mentioned in the earlier pages, the specimen was subjected to a constant initial maximum torsional stress of 19,560 lb. (8.7 tons) per sq. in. This was strictly observed throughout the whole of this section of the work.

Temperature/percentage-specific-damping-capacity curves are also recorded, the damping capacity in all such curves referring to a constant fibre stress of 13,000 lb. (5.8 tons) per sq. in. This stress corresponds to an overall amplitude of 4.0 cm. on the record, and was selected as a value at which the records could be accurately measured.

Wherever the records were taken by mechanical means, reference will be made to the fact, otherwise they all represent optically recorded results.

Finally, since the full interpretation of the results is as yet

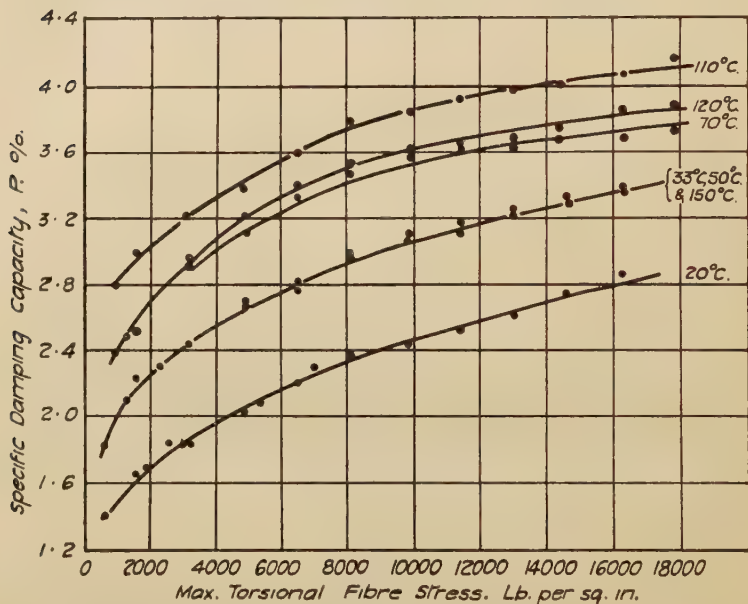


FIG. 18.—0.2% Carbon Steel, hot-rolled.

uncertain, the full curves of damping capacity against maximum fibre stress have been given in all cases. This procedure appeared to be the only way of ensuring that the measurements could, in time at any rate, be compelled to yield all the information they have to give.

#### Composition.

Six materials have been examined, of which the Armco iron and the 0.2% and 0.9% carbon steels were supplied and tested in the hot-rolled state. The 3% nickel steel was in the quenched and tempered (sorbite) condition, the 0.4% carbon steel being slightly cold-rolled. In addition to examining the eutectoid steel as received, its properties were also investigated in the martensitic,



troostitic and sorbitic states, the heat treatments being, respectively, quenching in water from  $780^{\circ}\text{C}$ ., quenching followed by tempering at  $400^{\circ}\text{C}$ ., and tempering at  $500^{\circ}\text{C}$ . The 0.3% carbon steel was examined in the normalised condition, oil-quenched from  $850^{\circ}\text{C}$ ., and water-quenched and tempered at  $675^{\circ}\text{C}$ . for one hour. With regard to the cold-rolled 0.4% carbon steel, it may be pointed out

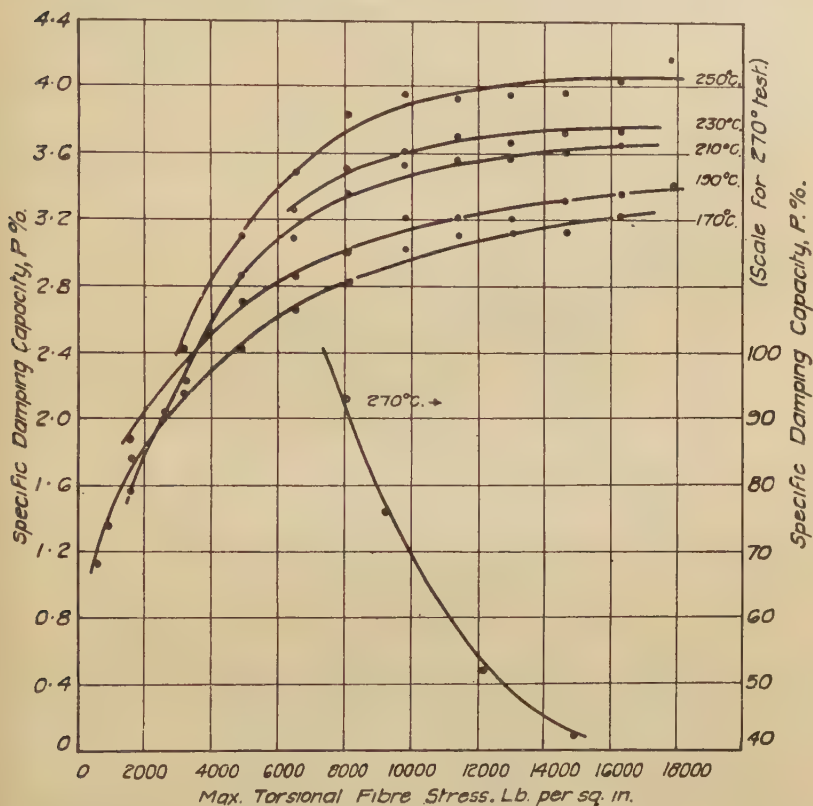


FIG. 19.—0.2% Carbon Steel, hot-rolled.

that the tests on this material were not carried out until at least a year had elapsed after the cold-rolling operation.

## RESULTS.

### 0.2% Carbon Steel.

Three sets of experiments were carried out, the first up to a maximum temperature of  $270^{\circ}\text{C}$ ., the second up to  $230^{\circ}\text{C}$ ., and the third up to  $150^{\circ}\text{C}$ . The results of the first run are given in Figs. 18 and 19. From these it will be seen that, up to  $250^{\circ}\text{C}$ ., the

damping capacity at any given temperature rises with the stress. At  $270^{\circ}\text{C}$ . (Fig. 19), however, the trend of the curve changes abruptly,  $P$  decreasing as the stress is increased. Further, whereas at  $250^{\circ}\text{C}$ .  $P$  is about 4.0% for a stress of 15,000 lb. per sq. in., it rises suddenly to over 40% for the same stress at  $270^{\circ}\text{C}$ . This difference is yet greater at still lower stresses. At  $250^{\circ}\text{C}$ . and for a stress of 8000 lb. per sq. in.,  $P$  is 3.7%, whereas at  $270^{\circ}\text{C}$ . it has risen to 93.0%, some 25 times its value only  $20^{\circ}\text{C}$ . lower. This phenomenon of a sudden increase of damping capacity at a temperature somewhere around  $250\text{--}300^{\circ}\text{C}$ . occurs in all the materials at slightly different temperatures and, broadly speaking, must be due to the sudden development of some sort of "plastic" condition.

With regard to the effect of temperature on the damping capacity, the curve (Fig. 20 (a)) shows a steady rise of  $P$  up to a temperature

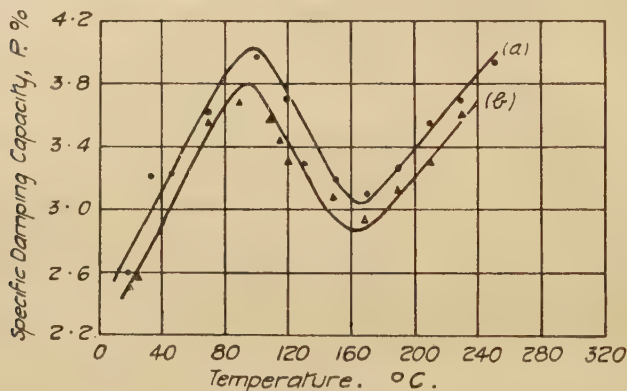


FIG. 20.—0.2% Carbon Steel, hot-rolled.

of about  $90^{\circ}\text{C}$ ., and then a fall to  $170^{\circ}\text{C}$ . Above  $170^{\circ}\text{C}$ .,  $P$  again rises up to  $250^{\circ}\text{C}$ ., after which, at  $270^{\circ}\text{C}$ ., as mentioned above, a sudden and very marked jump occurs. The results for a second set of experiments (Fig. 20 (b)), show that the values of  $P$  for a given stress have fallen as compared with the first results.

This drop in  $P$ , when the material is tested for the second time, *i.e.*, after having been already subjected to the maximum temperature, has been observed in other materials and will be referred to again later. Since the upper limit of temperature ( $290^{\circ}$  or  $310^{\circ}\text{C}$ .) to which the materials were heated in the present investigation, falls within the range of "blue brittleness," it would appear that the re-tested material has been stiffened thereby. That the change in the damping values of the second set of tests was not due to exceeding the elastic limit during the first series is shown by the fact that the values of  $P$  in curve (b) (Fig. 20) are consistently lower than those for curve (a). It has already been shown (Fig. 17) that the effect of

overstraining is to raise the damping capacity and not to lower it. Further, the value of the initial stress, about 8.7 tons per sq. in., was chosen, amongst other things, for the fact that this represents the elastic limit of such a steel at a temperature of 300° C.<sup>(22)</sup> In these tests, the highest temperature used was only about 250° C.

A third set of tests was made to see if there was any further change, but the values obtained were almost identical with those of the second.

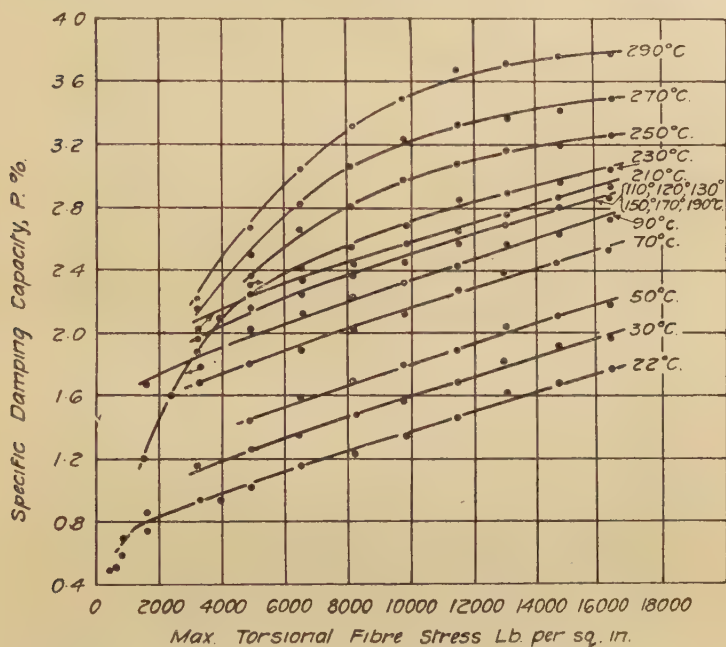


FIG. 21.—0.9% Carbon Steel, hot-rolled.

### 0.9% Carbon Steel.

The general shape of the curves (Figs. 21 to 23) for the eutectoid steel is similar to those for the 0.2% carbon steel. The damping values for the latter material are, however, in all cases much higher than the corresponding ones for the harder steel. Thus whereas the specific damping capacity of 0.2% carbon steel at 20° C. is over 2.6% for a stress of 13,000 lb. per sq. in., it is reduced to less than 1.6% in the case of the steel, with 0.9% carbon at the same stress and temperature.

A feature of Fig. 21 which is by no means uncommon is the manner in which some of the high-temperature curves cross others

at low stresses. The curves for  $90^{\circ}\text{C.}$  and  $230^{\circ}\text{C.}$  may be compared in this connection.

Another conspicuous difference between the results for the two materials is that, as Fig. 23 shows, there is a general rise in  $P$  with temperature with no peak at around  $90\text{--}100^{\circ}\text{C.}$ , nor minimum at  $170^{\circ}\text{C.}$ , as is the case with the  $0.2\%$  carbon steel (*cf.* Figs. 23 and 20). Briefly,  $P$  increases steadily up to  $120^{\circ}\text{C.}$ , after which it

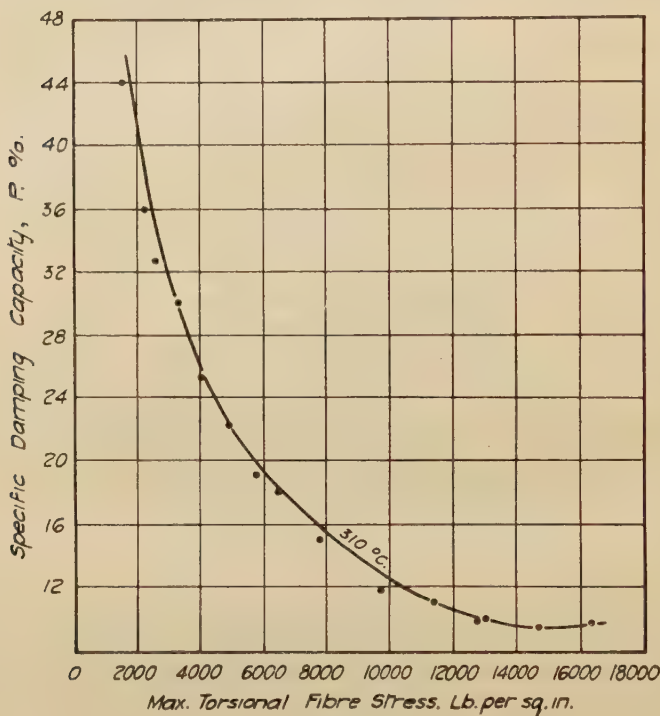


FIG. 22.— $0.9\%$  Carbon Steel, hot-rolled.

remains roughly constant to  $190^{\circ}\text{C.}$ , above which temperature it again rises steadily to  $290^{\circ}\text{C.}$  At  $310^{\circ}\text{C.}$  a sudden marked increase in  $P$  takes place, Fig. 22, corresponding to that at  $270^{\circ}\text{C.}$  in the case of the  $0.2\%$  carbon steel. A comparison of Figs. 19 and 22 will show that in both cases, when the temperature corresponding to the large rise in damping capacity has been exceeded, the shape of the curve becomes of a totally different character,  $P$  decreasing as the maximum fibre stress is raised. In the case of the curves of this character, the remarks made regarding the probable value of  $P$  at zero stress in discussing the shape of the specimen may require some

modification. Instead of this being quite small, as is normally the case, it will—unless the curve takes some completely new shape at low stress values—be very high indeed. The shape of the curve of Fig. 22 is roughly a rectangular hyperbola, which might suggest that steels at temperatures above this critical change-point may, at very low values of stress, have an almost infinite damping capacity. No explanation can as yet be offered of the radical difference of the curves at 310° C. for the 0.9% carbon steel and at 270° C. for the low-carbon material as compared with those obtained for lower temperatures. They were, however, confirmed by repeated tests

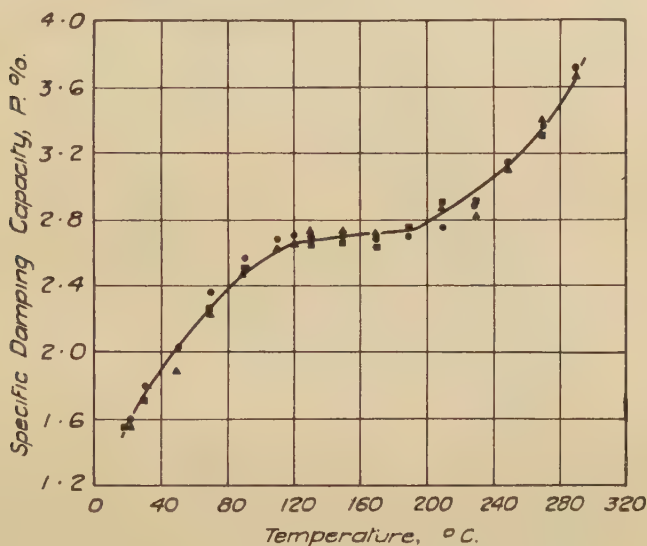


FIG. 23.—0.9% Carbon Steel, hot-rolled.

and the authors have no reason to doubt their reliability. The remarks made concerning the elastic limit apply here also.

The results of a second, third and fourth set of tests gave, within the experimental error, results practically identical with those of Figs. 21 and 22.

#### *Armco Iron.*

The curves for this material are given in Figs. 24 to 27. As will be seen from Figs. 24 and 25, the shape of the curves for this material is appreciably different from those of the two steels so far examined. In all cases these curves consist of an essentially straight line up to a stress around some 6000 lb. per sq. in., a second straight portion extending up to the highest stress measured, the two merging into



each other by a smooth curve. For the low stresses the curves tend to approach each other, while at higher stresses the lines diverge more and more as the temperature rises. That the break occurs in all of the curves, irrespective of the temperature, at a stress of about 6000 lb. per sq. in. is noteworthy. Amongst all the materials tested

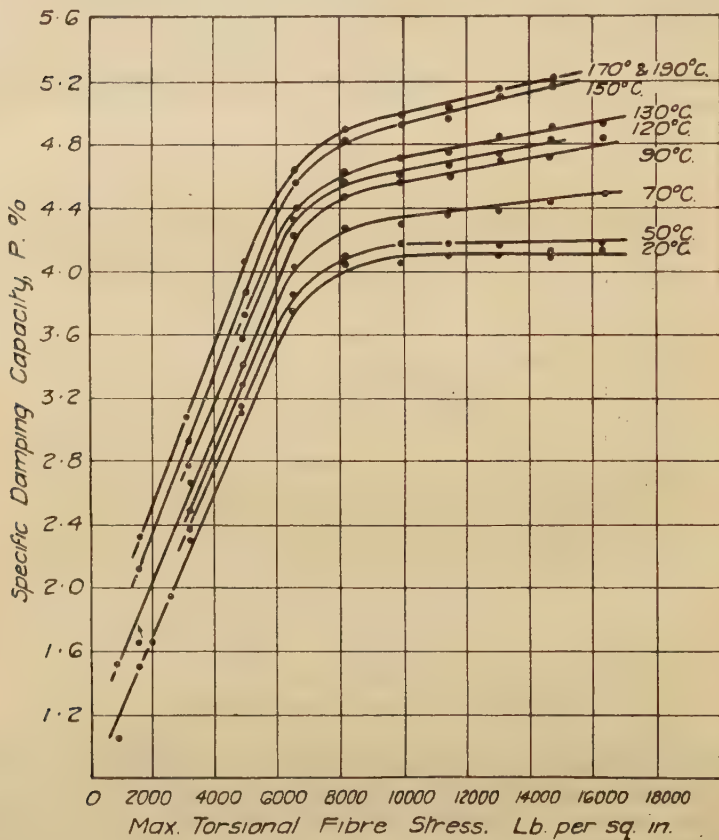


FIG. 24.—Armco Iron.

during the present work, the damping capacity of Armco iron is by far the highest. Chevenard<sup>(23)</sup> has already pointed out that the chemically simple steels might be expected to have higher damping capacities than those more highly alloyed.

The temperature/percentage-damping-capacity relationship for two runs is shown in Fig. 26. Although there are no peaks or depressions as in the case of 0.2% carbon steel, the curves are by no means regular. Another outstanding feature is that there is no

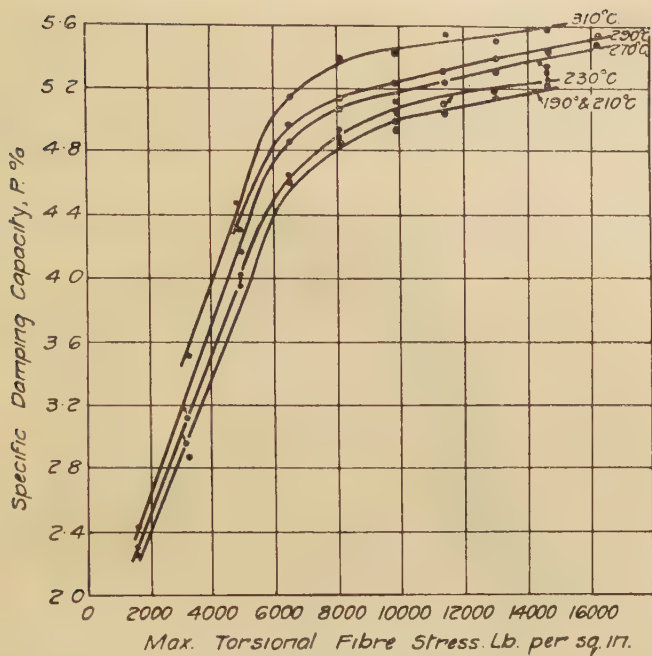


FIG. 25.—Armco Iron.

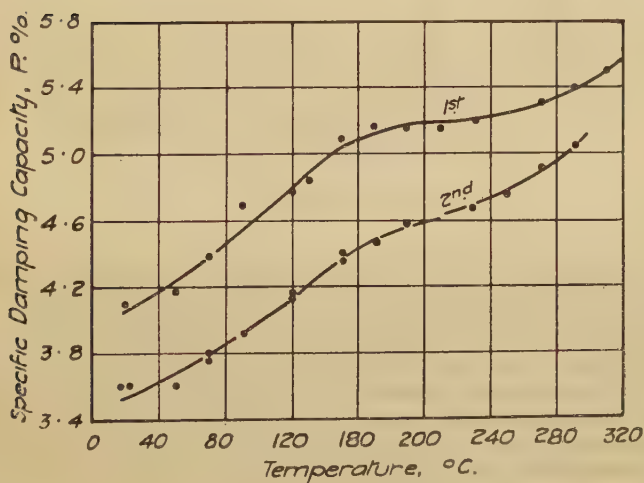


FIG. 26.—Armco Iron.

sudden rise in  $P$  around  $300^{\circ}\text{C}$ . as might have been anticipated from the behaviour of the 0.2% and 0.9% carbon steels, although the abnormal behaviour of Armco iron in many respects is quite well known. This absence of a sudden rise in the damping capacity of Armco iron causes the curve for this material to change its position relative to those of the other steels at the highest temperatures employed.

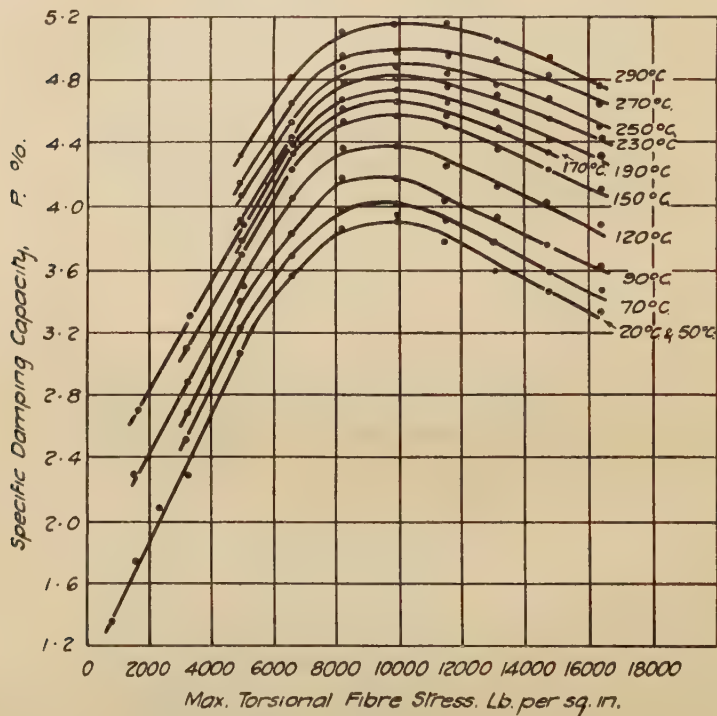


FIG. 27.—Armco Iron.

As in the case of the 0.2% carbon steel, the second set of tests (Figs. 26 and 27), shows a drop in the damping capacity, as compared with the first, the decrease, however, being far more pronounced. The shape of the new curves is, further, markedly different from those of the first set. A maximum value of  $P$  is reached at about 9000–10,000 lb. per sq. in. of torsional stress, after which  $P$  falls again as the stress is increased. This behaviour is not confined to any one temperature, all the curves from  $20^{\circ}$  to  $290^{\circ}\text{C}$ . being more or less parallel. The results of a third set of experiments were almost identical with those of Fig. 27.

*3.0% Nickel Steel.*

Unlike the three materials so far examined, this steel was tested in the quenched and tempered (sorbitic) condition. The values of  $P$  (Fig. 28) are, for the same stress and temperature, less even than those for the 0.9% carbon steel. The general effect of an increase of temperature, as is shown in Fig. 29, is to cause a continuous and increasingly rapid rise of damping capacity, and in this respect differs from its influence on the 0.2% and 0.9% carbon steels. There is, however, a very faint suggestion of slightly higher values of  $P$  between 120° C. and 190° C. The re-tested sample shows a fall of

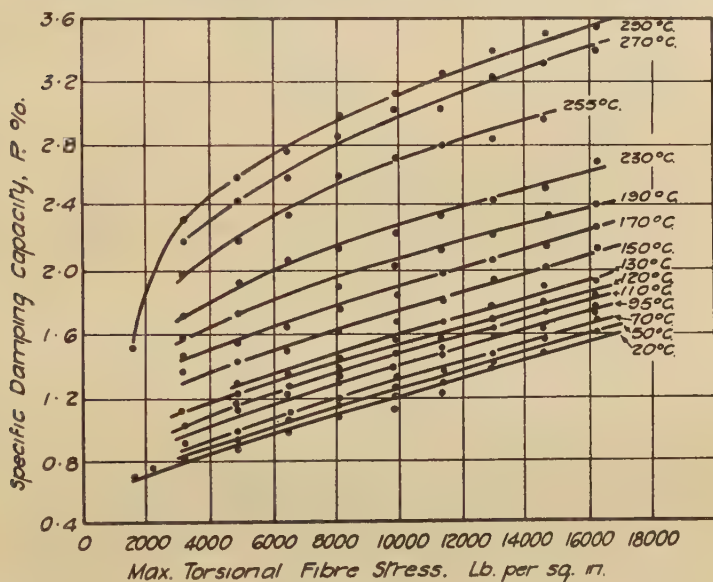


FIG. 28.—3.0% Nickel Steel.

$P$  as compared with the values of Fig. 28, especially in the lower temperature range.

## DAMPING PROPERTIES OF THE VARIOUS CONSTITUENTS OF STEEL.

From the tests on Armco iron and the 0.9% carbon steel, a general idea of the damping properties of ferrite and pearlite had been obtained. It appeared to be of interest to amplify such knowledge by tests on totally martensitic, troostitic and sorbitic steels. For this purpose a test-piece of the eutectoid steel was first hardened and subsequently, after the tests had been carried out on it in this state, tempered in two stages to get troostitic and sorbitic structures.

The specimen was suspended vertically in an electric furnace closed at both ends by asbestos fibre, heated to  $780^{\circ}\text{C}.$ , kept at that temperature for half an hour and then quenched vertically in cold

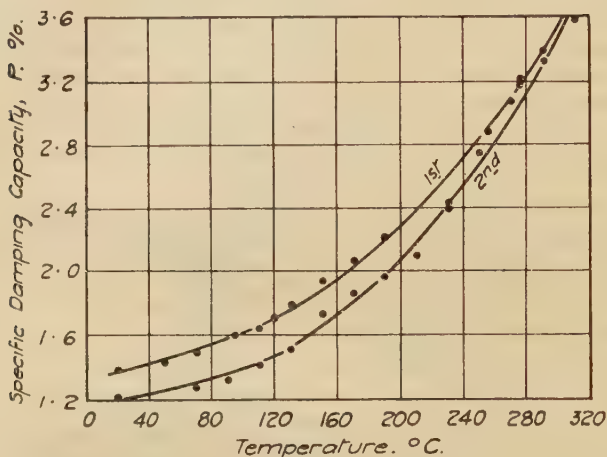


FIG. 29.—3.0% Nickel Steel.

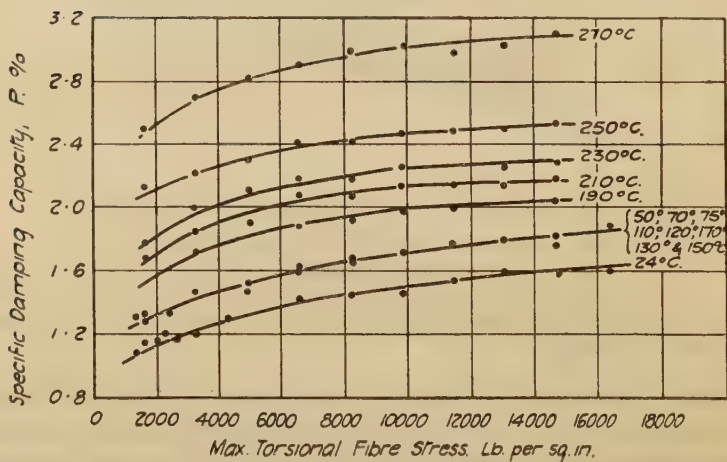


FIG. 30.—0.9% Carbon Steel, quenched from  $780^{\circ}\text{C}.$

water. The distortion was negligible and the thin film of oxide produced was removed on fine rouge paper. The structure obtained in the machined part of the bar was completely martensitic.

After being tested in this state, the bar was reheated in the same



furnace to a temperature of  $400^{\circ}\text{C}$ . for one hour and air-cooled. The structure, though of a more or less troostitic nature, was hardly typical; a rather lower tempering temperature would have been desirable. After these tests had been carried out, the specimen was re-tempered as before, but at a temperature of  $500^{\circ}\text{C}$ ., in which state a fine sorbitic structure was obtained.

### 0.9% Carbon Martensitic Steel.

The results are given in Fig. 30, the curves being generally similar in shape to those obtained for the material in the pearlitic state.

The somewhat flattened nature of the curves indicates that, unlike the materials previously examined, the damping capacity of

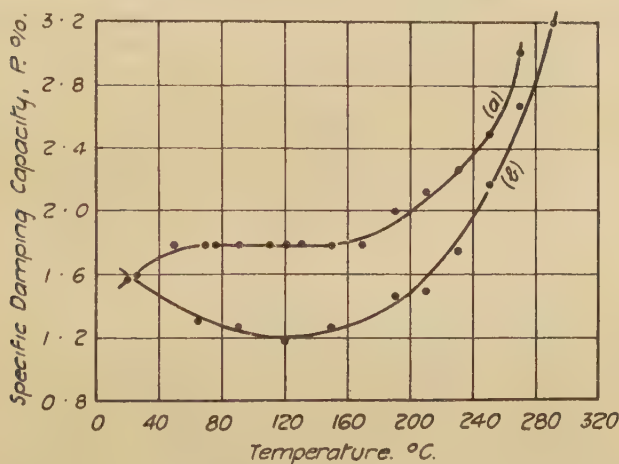


FIG. 31.—0.9% Carbon Steel, quenched from  $780^{\circ}\text{C}$ .

this steel at high stress varies comparatively little from that at lower ones. This effect, as will be shown later, becomes still more pronounced in the case of the "troostitic" and sorbitic materials.

Regarding the influence of temperature, the curve for the first run, Fig. 31 (a), shows that  $P$  rises slightly with temperature up to about  $70^{\circ}\text{C}$ ., after which it remains constant to about  $170^{\circ}\text{C}$ . Above  $170^{\circ}\text{C}$ .,  $P$  again rises more and more rapidly as the temperature is increased up to  $270^{\circ}\text{C}$ .

The results of a second set of tests are given in Fig. 31 (b), and represent the damping capacity of the above specimen as tempered at  $270^{\circ}\text{C}$ . There is no longer any tendency for  $P$  to remain constant over a certain range of temperature, the damping capacity falling to a minimum at  $120^{\circ}\text{C}$ ., after which it again rises.

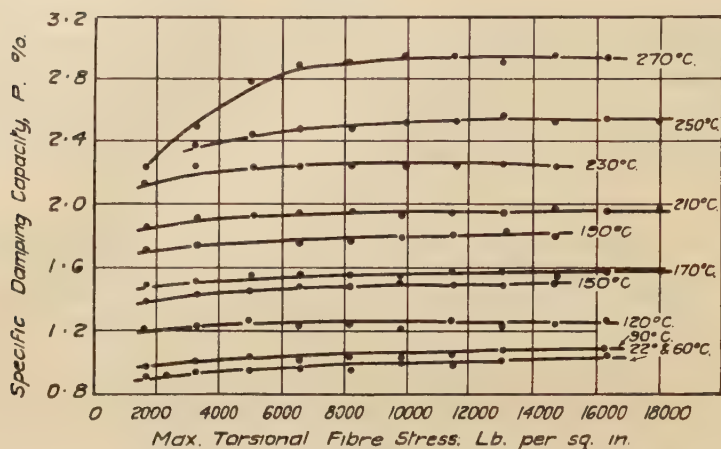


FIG. 32.—0.9% Carbon Steel, quenched from 780° C., and tempered at 400° C.

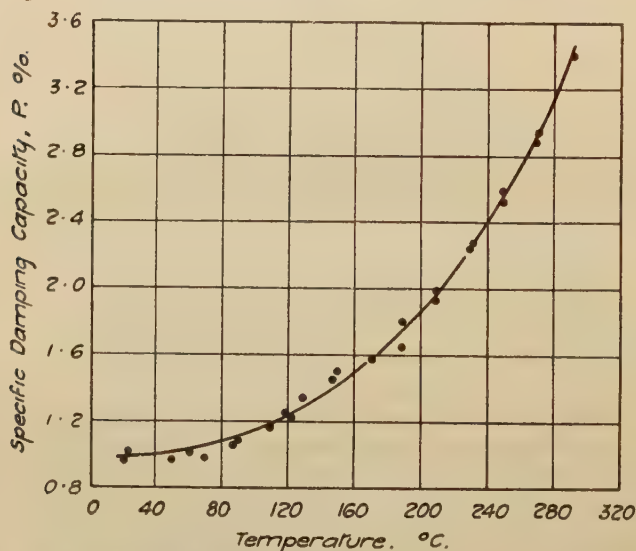


FIG. 33.—0.9% Carbon Steel, quenched from 780° C., and tempered at 400° or 500° C.

#### 0.9% Carbon Troostitic Steel.

Fig. 32 shows the results for this steel, a damping-capacity/temperature curve being given in Fig. 33. From the results it will be seen that below about 230° C.  $P$  is invariably lower than in the

case of the originally martensitic sample. Above this temperature the differences are small. The damping capacities at room temperature are, for a given stress, the lowest for any of the materials tested during the present work.

### 0.9% Carbon Sorbitic Steel.

The curves are shown in Fig. 34. In Fig. 33 the results for this, as well as those for the troostitic specimen, are plotted, the two sets of determinations practically coinciding.

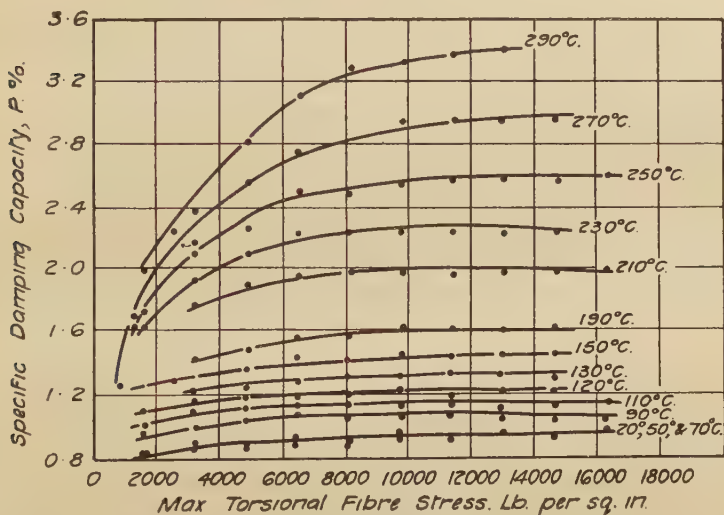


FIG. 34.—0.9% Carbon Steel, quenched from 780° C., and tempered at 500° C.

### 0.4% Carbon Steel.

Prior to the introduction of the optical method of recording, a large number of experiments were carried out with the original stylus-recording system to study the effect of temperature on a cold-rolled 0.4% carbon steel.

The mechanical recording system, although it gives systematically high results, does not affect the essential form of the curve, nor, since the separate curves are displaced by a more or less constant amount, does it appreciably affect their relative positions. It is possible, therefore, to study the general behaviour of the differently heat-treated materials from these curves, although a very substantial correction factor would have to be introduced to give the absolute values of  $P$ . The actual  $P$ /stress curves are not, therefore,

reproduced here, only the temperature relations after different heat-treatments being shown in Fig. 35.

The results of the first three sets of experiments on the material in the as-received condition are given in the identical curves (1), (2) and (3) of Fig. 35, no change in  $P$  being observed after the first or the second set of tests. A sudden jump to a very high value of damping capacity was observed at  $330^{\circ}\text{C}$ . After these series of tests the specimen was vacuum-annealed<sup>(25)</sup> at  $780^{\circ}\text{C}$ . and furnace-cooled. The microsection, etched with sodium picrate, Fig. 43, shows that the rate of cooling of the steel was very slow, giving a

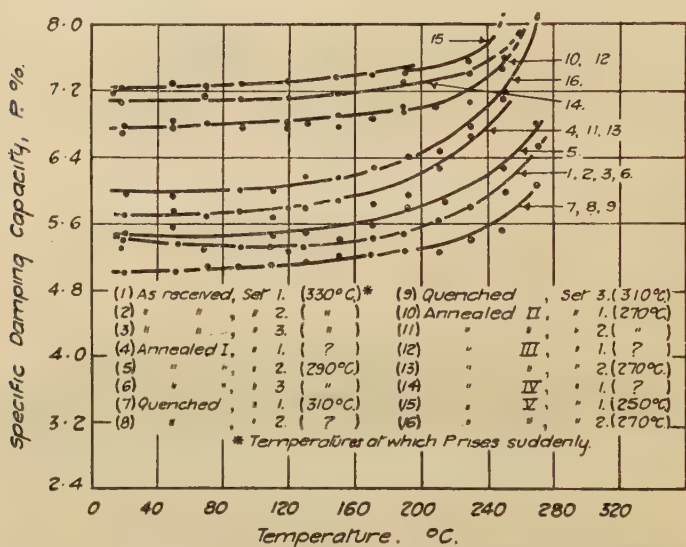


FIG. 35.—0.4% Carbon Steel, cold-rolled. Specific damping capacities corresponding to a stress of 13,000 lb. per sq. in.

structure of fine particles of coalesced carbide in a ground-mass of ferrite.

The results of the first set of tests carried out on the steel in this state are given in Fig. 35, curve (4). The values of  $P$  are distinctly higher than those in the as-received condition and, as curve (5) shows, the results of the second set are below those of curve (4), though still higher than those of curves (1) to (3). When re-tested for a third time, curve (6), the value of  $P$  has dropped still further, until it is almost identical with that for the original material. As a result of this annealing treatment, the temperature at which the sudden jump in  $P$  takes place has fallen from  $330^{\circ}$  to  $290^{\circ}\text{C}$ .

**Quenching.**—In order to examine the effect of internal stresses

on the damping capacity, the same specimen was then water-quenched from  $700^{\circ}\text{C.}$ , *i.e.*, below the  $\text{Ac}_1$  point. As may be seen from curve (7), the effect of quenching has been to lower the specific damping capacity even below that in the cold-rolled state, and as curves (8) and (9) show, there is no further change in  $P$  when the specimen is subsequently re-tested after being heated to about  $300^{\circ}\text{C.}$  In this respect, it differs essentially from the annealed specimen, where  $P$  drops progressively during the second and the third set of tests. The temperature at which a sudden jump in  $P$  takes place has risen to  $310^{\circ}\text{C.}$ , as compared with  $290^{\circ}\text{C.}$  in the case of the annealed material.

The same specimen was then again vacuum-annealed as before, the results being given in curves (10) and (11). The annealing has raised the damping capacity to a value higher than that obtained after first treatment, curve (4), though when re-tested, curve (11), values of  $P$  are obtained which coincide with those of curve (4).

A third annealing treatment similar to the first and second gave results, curves (12) and (13), which are identical with those obtained after the second annealing.

It has been abundantly shown that in all normal cases the damping capacity rises as the maximum fibre stress is increased. This maximum fibre stress clearly occurs at the surface. It would appear to follow, therefore, that any treatment which appreciably affects the surface structure would be expected to have a considerable effect upon the damping value.

To examine this point the specimen was again annealed at  $780^{\circ}\text{C.}$  for 14 hr. under conditions such that a certain amount of superficial decarburisation occurred and was then slowly cooled. The structure after treatment, Fig. 44, consists of coalesced particles of carbide, mainly at the crystal boundaries, in a relatively coarse-grained ferritic matrix. The results of two series of tests are recorded in Fig. 35, curves (15) and (16). For the first run, curve (15), the values of  $P$  are the highest of any obtained on this material. Curve (16) shows the drop which is common to the lower-carbon steels on re-testing, though the values are still above those for the first annealing, curve (4).

The results do, therefore, correspond with those to be expected from decarburised samples when the high damping capacity of ferrite is borne in mind. It must, however, be pointed out when the results of the first and last sets of curves on the annealed material are compared, that there is also a very distinct increase in grain size, which may also exert its own influence upon the value of  $P$ .

Through the kindness of Dr. H. O'Neill, samples were available for test of steel of the following composition : carbon 0.30%, silicon 0.16%, manganese 0.73%, sulphur 0.03%, phosphorus 0.042%. The samples were oil-quenched from  $850^{\circ}\text{C.}$ ; water-quenched from the same temperature and tempered for one hour at  $675^{\circ}\text{C.}$ ; and normalised from  $850^{\circ}\text{C.}$  respectively. The stress/damping-capacity



curves for a range of temperature are shown in Figs. 36 to 38, whilst in Fig. 39 the results for an initial stress of 19,000 lb. per sq. in. and a fibre stress of 13,000 lb. per sq. in. are recorded.

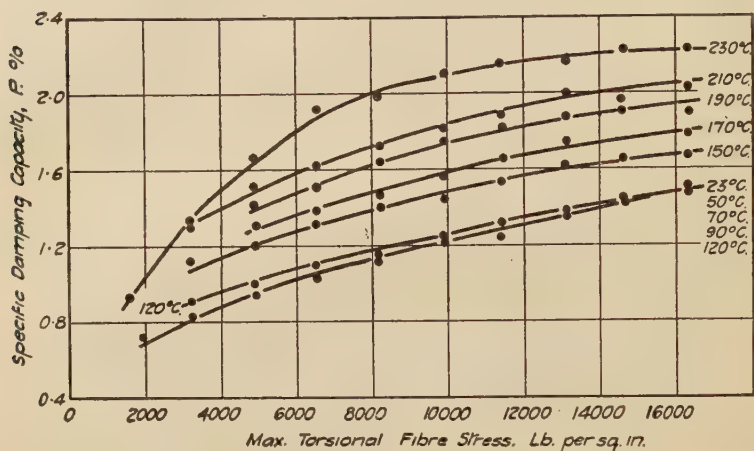


FIG. 36.—0.3% Carbon Steel, oil-quenched from 850° C.

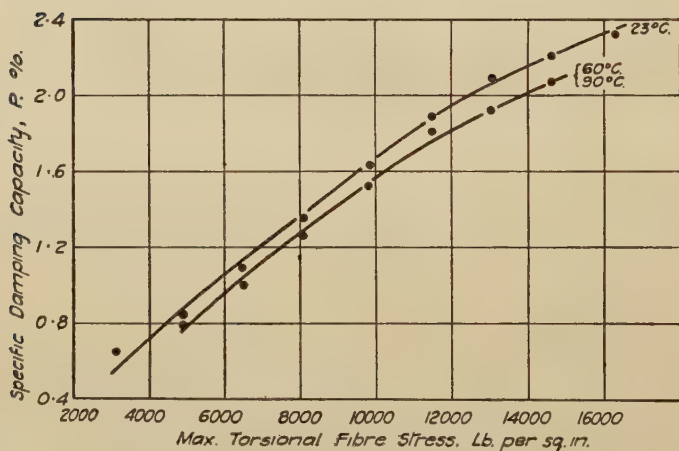


FIG. 37.—0.3% Carbon Steel, water-quenched from 850° C., and tempered 1 hr. at 675° C.

The relatively high values of  $P$  for the normalised steel will be noted, together with the fact that there appears to be no marked inflexion corresponding to that obtained with the 0.2% carbon steel in the temperature range from 100° to 170° C.

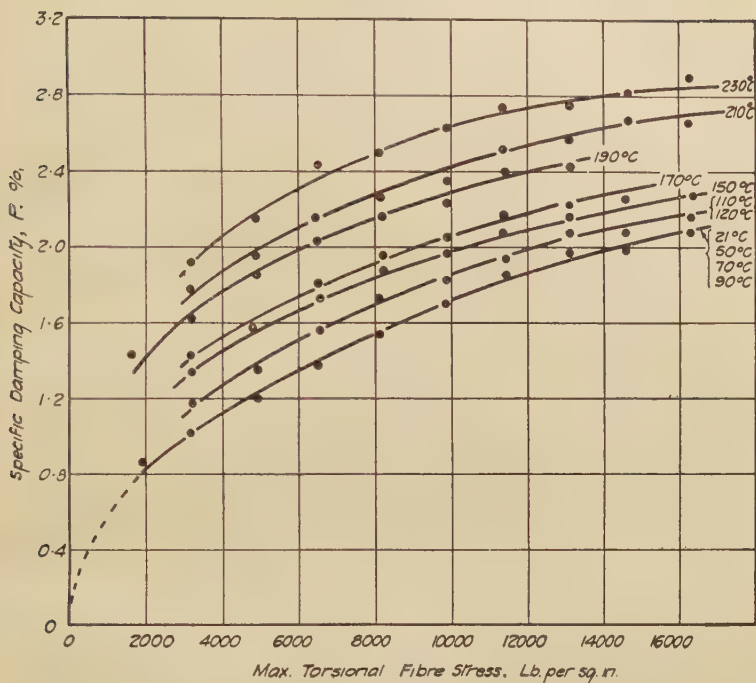


FIG. 38.—0.3% Carbon Steel, normalised from 850° C.

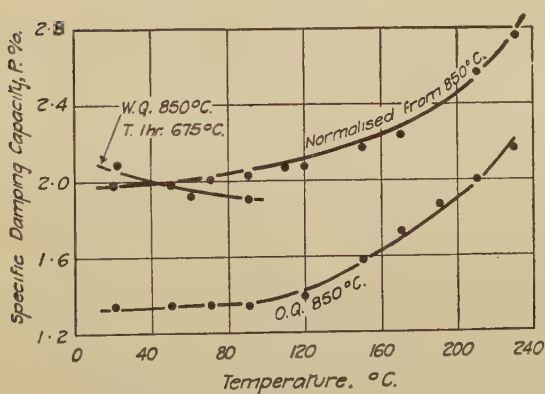


FIG. 39.—0.3% Carbon Steel.

## CONCLUSIONS.

It must again be emphasised that the scope of this work covers only the collection and, to some extent, the correlation of experimental data with regard to the damping capacities of a few steels at moderate temperatures, and that it would, as yet, be premature to attempt to offer any explanation of the results.

(1) The apparatus employed was designed on lines very similar to those of the Föppl-Pertz machine. Since, however, it was found that any mechanical method of recording the torsional oscillations gives unexpectedly high damping values, due to the friction between the stylus and the moving strip of paper, an optical arrangement was substituted which eliminates loss from this cause.

Another important modification was the use of a self-aligning journal system to support the inertia bar and the upper end of the specimen. By this means, the serious error introduced into the measurements due to even slight bending of the specimen was removed. It has been shown, however, that more marked bending still results in a considerable increase in the apparent value of  $P$ .

The authors have confirmed the absolute necessity of suspending the whole apparatus as freely as possible.

(2) Other points in the measurement of damping capacity which need careful attention if accurate results are to be obtained are :

(a) The grips and the ends of the specimens must be kept clean and free from grit and scale respectively, the presence of which would impose an additional bending moment on the specimen and hence lead to unduly high results. The authors have assumed in work of this kind that extraneous losses of energy, leading to an increase in the apparent value of  $P$ , may be expected; it is difficult, however, to visualise any experimental conditions such that the damping capacity is reduced below its true value.

(b) Careful and standard machining of the specimen, especially the shoulders, is very important. The specimen should be as free as possible from distortion, a matter at times of some difficulty where cold-drawn or other internally stressed steels are concerned.

(c) With the apparatus used in this work, the results are not affected by the change in size of the specimen, or of the alteration of frequency (within the range investigated) which results therefrom.

(d) The specimen must be firmly gripped in the machine, or energy losses occur which lead to excessively high values of the apparent damping capacity.

(e) For a given maximum fibre stress, the value of the damping capacity is a function of the torsional stress to which the specimen was initially subjected. For a given fibre stress, the damping capacity is higher as the initial stress is reduced and *vice versa*. This was found to be especially important for specimens having the shorter gauge length of 2 in. With the long specimens the extent of this variation was, however, small.

(f) The damping of the first test of a new specimen was usually, though not invariably, higher than that of subsequent ones. For the purposes of this research the results recorded are those of the fourth and following runs which are essentially identical.

(g) Overstrain of the material prior to, or during, test increases the value of  $P$ , especially for the higher fibre stresses.

(3) With the modified apparatus employed and with the experimental precautions outlined above, very consistent results have been obtained. This will be seen from curves (1), (2), (3), and (7), (8) and (9) respectively of Fig. 35 and, even where slightly different experimental conditions prevailed, in Figs. 10, 12A, 14 and 16.

It has not been possible to determine the order of the error introduced into the results due to the resistance of the air to the movement of the inertia bar. Since, however, values of  $P$  of the order of 0.4% have been obtained on several occasions, this is the maximum uncertainty due to this and all other causes.

Another point which has not been taken into account in the case of the higher-temperature tests is the variation with temperature of the elastic properties of the steels. It has been shown that the value of the maximum fibre stress is a function of the modulus of rigidity. The latter clearly changes with temperature, but no account of this has been taken in the present work, first, because of the very great amount of work which would have been involved in determining this modulus for each of the steels and for all of the temperatures investigated, and secondly, as a result of the fact that the magnitude of the error involved is not likely to be sufficiently large to require any appreciable modification of the conclusions to which this work has led.

In all but a few exceptional cases, the damping-capacity/fibre-stress curves rise with increasing stress. The question then arises as to the probable value of  $P$  for zero stress. It has been shown, Figs. 5 and 14, that at stresses as low as 500 lb. per sq. in., and, in one or two instances, even down to 200 lb. per sq. in., the damping capacity measured has a definite, positive value. It is, therefore, clear that either a value around 0.4% represents the total of the experimental errors in this work, all of which would act in the same direction and increase the measured value of  $P$ , or that all of the materials examined give a mechanical hysteresis loop for all stresses, however low.

The exceptions to the normal curve, giving decreasing values of  $P$  as the stress rises, are the following: (a) When the apparatus is standing on a table and (b) when the specimen is only loosely gripped in the machine—both cases in which successive energy is lost during test; (c) the 0.2 and 0.9% carbon steels at temperatures above that at which the damping capacity undergoes a fairly sudden and relatively enormous increase, and (d) the vacuum-annealed Armco iron at fibre stresses above 9000 lb. per sq. in.

Both the radical change in the shape of the curve, Figs. 19 and 22, and the variation of the temperature at which it occurs in different steels indicate clearly that it is not a question merely of exceeding the "elastic limit," but apparently of some inherent change in the properties of the material. If the behaviour of Armco iron and the 0.9% carbon steel, for instance, is considered in relation to the values of their limits of proportionality and the initial stress of 8.7 tons per sq. in., the former is stressed much above its elastic limit—about 4 tons per sq. in. at 300° C.—by the initial stress and yet shows no signs of the reversal of the curvature, whilst the 0.9% carbon steel, on the other hand, which has not been stressed up to its limit of proportionality, shows a clear reversal at a temperature around 300° C.

That there is, however, apart from the Armco iron, some general relationship between the ordinary mechanical properties and the temperature at which the change occurs will be evident from Table I.

TABLE I.—*Relation between Ordinary Mechanical Properties and the Temperature at which the Change in Damping Capacity Occurs.*

Material.	Condition.	Temperature. °C.
0.4% carbon steel.	Cold-rolled.	330
Armco iron.	As received.	} > 310
3% nickel steel.	Quenched and tempered.	
0.9% carbon steel.	As received.	} 310
0.4% carbon steel.	Quenched 700° C.	
0.4% carbon steel.	First anneal.	290
0.2% carbon steel.	As received.	} 270
0.4% carbon steel.	Third anneal.	
0.4% carbon steel.	Fifth anneal for 15 hr.	250

(4) For a given stress low-carbon steels have higher damping capacities than harder ones. Broadly speaking, the damping at room temperature decreases as the carbon content increases, provided the material is similarly heat-treated (Fig. 40). There is good reason to believe, however, that factors such as grain size, structure, surface decarburisation and the previous history of the material also influence the results.

As a result of the overlapping of the curves, however, it is not possible to place the materials investigated in any definite order so far as their damping capacities are concerned unless some arbitrary value of stress is chosen. In Table II. typical results for a range of stress and at three different temperatures have been collected.



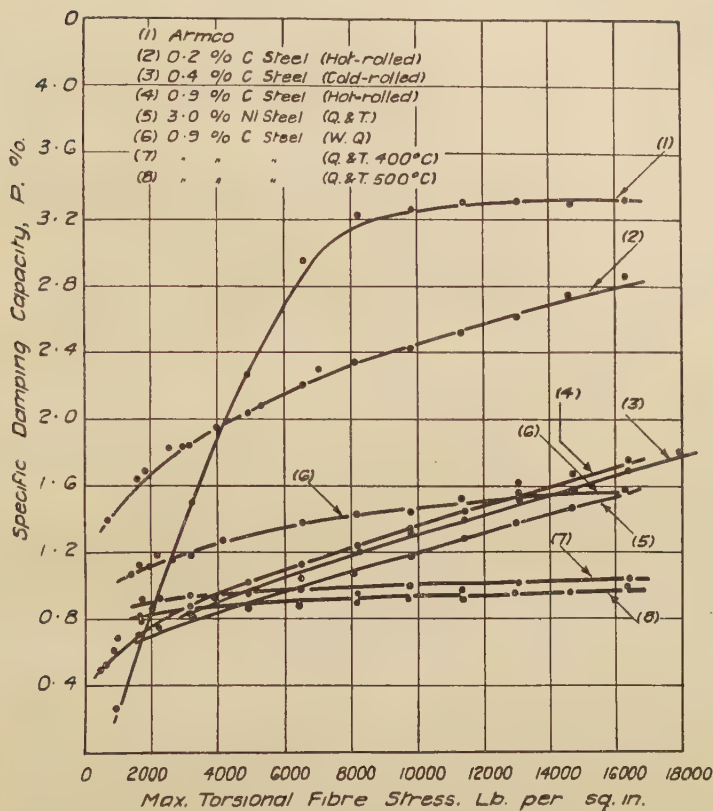


FIG. 40.

TABLE II.—*Typical Results for the Damping Capacity at Different Temperatures for a Range of Stress.*

Material.	Condition.	Maximum Fibre Stress, lb. per sq. in., at—								
		20° C.			110° C.			230° C.		
		5000.	10,000.	14,000.	5000.	10,000.	14,000.	5000.	10,000.	14,000.
		Damping Capacity. %.								
Armco iron.	As received.	3.08	4.10	4.11	3.60	4.62	4.75	4.06	5.07	5.23
0.2% carbon steel.	As received.	2.07	2.45	2.69	3.44	3.84	4.00	3.00	3.60	3.72
0.3% carbon steel.	Normalised	1.24	1.72	1.98	1.40	1.86	2.09	2.19	2.64	2.80
0.9% carbon steel.	As received.	1.06	1.37	1.63	2.14	2.50	2.74	2.26	2.71	2.94
0.3% carbon, 3% nickel steel.	Quenched and tempered.	0.90	1.19	1.43	1.15	1.47	1.69	1.90	2.28	2.52

These all apply to determinations carried out, as has been mentioned previously, with a constant initial stress of 19,560 lb. per sq. in. and a fibre stress of 13,000 lb. per sq. in. The consistently high values for the iron, and the low ones for the sorbitic nickel steel will be evident.

(5) Passing on to consider the damping properties of the different constituents of steel, it will be seen from Table III. that the martensitic sample had at room temperatures and for the lower stresses

TABLE III.—*Damping Properties of the Different Constituents of Steel for a Range of Stresses at Three Different Temperatures.*

Material.	Heat Treatment.	Maximum Fibre Stress, lb. per sq. in., at—								
		20° C.			110° C.			230° C.		
		5000.	10,000.	14,000.	5000.	10,000.	14,000.	5000.	10,000.	14,000.
Damping Capacity, %.										
Ferrite = Armco iron.	As received.	3.08	4.10	4.11	3.60	4.62	4.75	4.06	5.07	5.23
Pearlite = 0.9% carbon.	As received.	1.06	1.37	1.63	2.14	2.50	2.74	2.26	2.71	2.94
Martensite = 0.9% carbon.	W.Q. 780° C.	1.32	1.50	1.60	1.52	1.71	1.82	2.06	2.25	2.29
Troostite = 0.9% carbon.	W.Q. 780° C., T. 270° C.†	1.34	1.51	1.57	0.92	1.08	1.18	1.51	1.67	1.75
0.9% carbon.	W.Q. 780° C., T. 400° C.	0.94	0.99	1.02	1.20*	1.20*	1.20*	2.22	2.26	2.25
0.3% carbon.	O.Q. 860° C.	0.95	1.22	1.39	1.02	1.25	1.41	1.66	2.10	2.20
Sorbite = 0.9% carbon.	W.Q. 780° C., T. 500° C.	0.89	0.95	0.96	1.12	1.16	1.16	2.10	2.27	2.26
0.3% carbon.	W.Q. 850° C., T. 675° C.	0.90	1.66	2.16	0.78*	1.56*	2.01*	...	...	...

\* Estimated,

† From unpublished curves.

a higher value of  $P$  than that corresponding to the pearlitic state. At higher temperatures, however, this no longer holds.

Not only is the damping capacity associated with the troostitic and sorbitic structures low, but it also remains relatively constant at high and at low stresses. For example, in the case of the sorbitic 0.9% carbon steel,  $P$  at stresses of 2000 and 16,000 lb. per sq. in. is 0.82% and 1.0% respectively.

(6) The general effect of temperature, as is shown in Fig. 41, is to increase the damping capacity, although the curves are not always continuous and regular. Particularly is this the case with the 0.2% carbon steel. At temperatures of the order of 250–310° C. there is—except in the cases of the Armco iron and the sorbitic nickel steel—a relatively sudden and enormous rise in the damping value. Both composition and structure would appear to affect this phenomenon, but beyond the general statement that materials which are normally hard show the effect at a rather higher temperature than do softer ones, no useful generalisation can be made.

(7) It has usually been found to be the case that the damping-capacity determinations on a second or subsequent series of tests are lower than those given by the first. A possible explanation of this may be found in the fact that during the first run the sample

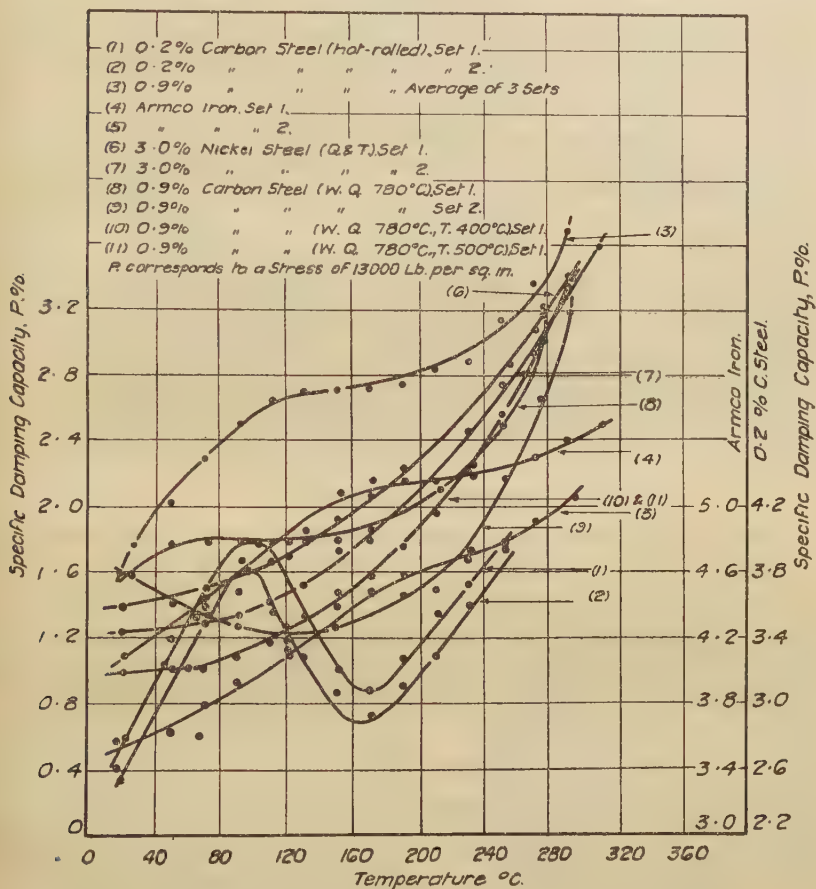


FIG. 41.

has been heated to temperatures within the "blue-brittle" range. It is of significance perhaps that this difference was greatest in the case of Armco iron.

(8) This research was commenced in the hope of obtaining another method of investigating the "low"-temperature change points in iron and steel. Although it has been shown that these

changes are not without their influence on the damping properties (Figs. 20, 23 and 26), it is clear that this method is, in general, unsuited to the subject under examination. At the same time and especially in the cases of the 0.2 and the 0.9% carbon steels, as Table IV. shows, there are points of such obvious similarity between the present results and those of Goffey and Thompson<sup>(26)</sup> for the torsional limits of proportionality of electrolytic iron and 1.0% carbon steels, that a common underlying cause can hardly be doubted.

TABLE IV.—*Comparison of the Points of Inflexion in the Damping Capacity Curves and the Torsional Limits of Proportionality of Two Carbon Steels.*

Material :	Carbon 0.2%.			Carbon 0.9%.		
Temperature.	90° C.	170° C.	270° C.	120° C.	190° C.	310° C.
Damping.	Max.	Min.	Sudden increase of <i>P</i> .	Change of direction.	Change of direction.	Sudden increase of <i>P</i> .
Limit of Proportionality.	Max.	Max.	Min.	Min.	Max.	Max.

#### ACKNOWLEDGMENTS.

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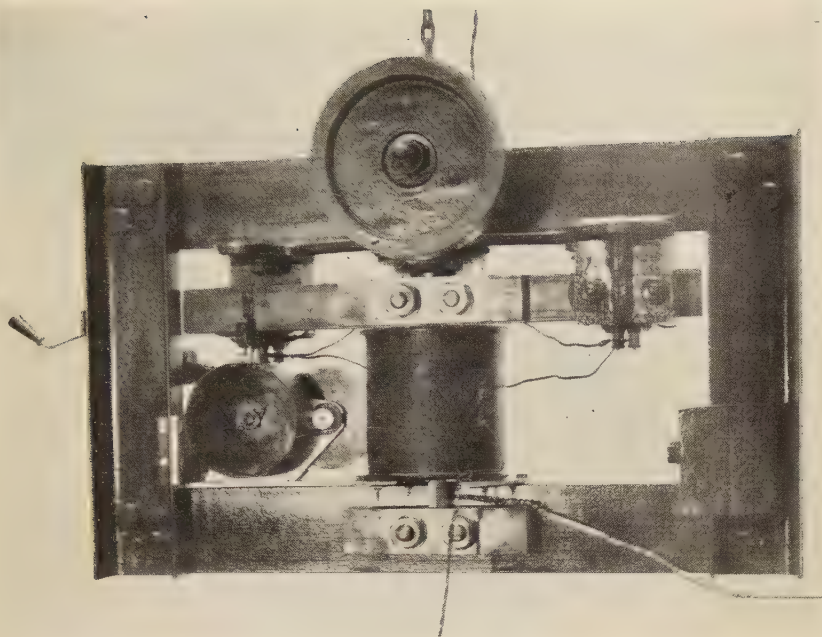


FIG. 42.—The Apparatus for Measuring Damping Capacity.

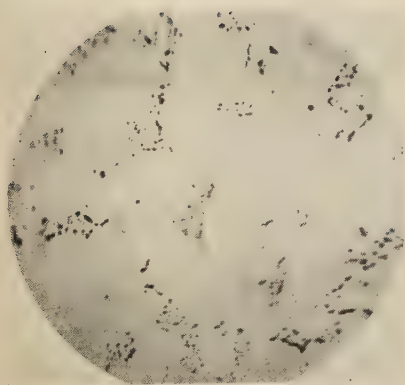


FIG. 43.—0.4% Carbon Steel, vacuum-annealed at 780° C. Etched with sodium picrate.

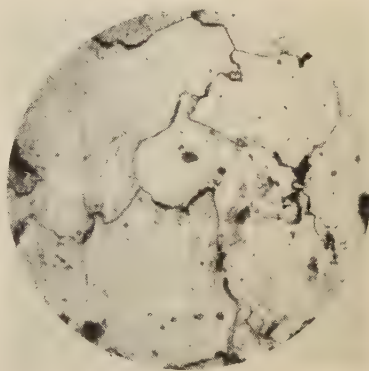


FIG. 44.—0.4% Carbon Steel, annealed at 780° C. for 14 hr. under conditions permitting slight surface decarburisation.

[Contractor & Thompson.  
[To face p. 200 p.]



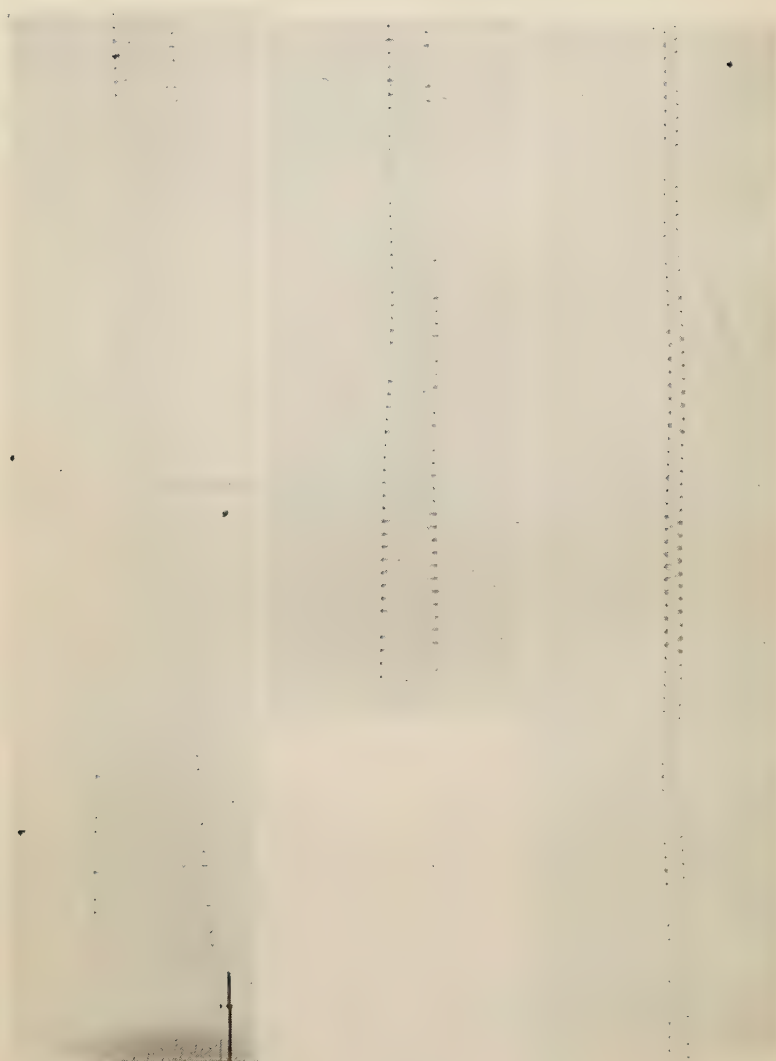


FIG. 45.—A Typical Record of Damping Capacity.

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*DISCUSSION.*

Dr. S. L. SMITH (Teddington, Middlesex) said that the subject of damping capacity was of interest both to the engineer and to the metallurgist, and a method was badly needed for accurately measuring this property of a material. The authors had made some modifications to the Föppl-Pertz apparatus and had shown that its accuracy was considerably improved thereby.

He thought it was very desirable that consideration should be given to the question as to what it was that one was trying to measure. Actually it was the area of the hysteresis loop under definite conditions of stress range, and the point was as to whether the method of measurement under discussion gave figures which were proportional to this area or not. Of course, it was known that the area of the hysteresis loop diminished with the number of repetitions, that was to say, with the first few repetitions it had a certain area and it did not stabilise until the specimen had gone through perhaps half a million repetitions. What the engineer really wanted to know, he thought, was the stabilised loop area under conditions of a definite stress range.

Another fact which it was important to remember was that the ratio of the loop area to the energy stored under various stress ranges was not constant and varied with the stress. Therefore the torsional method in itself was somewhat at a disadvantage, in the sense that the stress in the material was varying from zero at the centre to a maximum at the surface, and that factor was involved in all figures obtained by torsional methods. He felt, therefore, that in connection with the measurement of damping capacity what was really needed was a long-range research in which the stabilised area of the hysteresis loop for a given material was obtained for definite stress ranges, those stress ranges being actually, he thought, direct stresses and not torsional stresses. That research might be a fairly lengthy one, but he thought it would yield extremely important results and would serve as a basis to compare methods such as the one used by the authors.

The authors had succeeded in eradicating some serious sources of error in the original apparatus, particularly in the recording device. Fig. 8, for instance, showed that one method of recording actually used up four times as much energy in friction as the energy that was being measured. That strongly emphasised, he thought, the fact that no other means but an optical device was at all useful in any of the work in question.

There were certain points on which he would like to have some further information. First, he would like to ask whether the authors were sure that there was no residual magnetism remaining in the magnets after the release of the specimen when the experiment commenced. If there was, would it make any difference? Secondly, with regard to the self-aligning bearing which

was employed at the top of the specimen, one of course realised that the friction was probably a minimum, but had the authors any figures to show what that friction loss amounted to. Thirdly, he inferred from Fig. 1 that the optical recorder was really recording the strain over the whole length of the test-piece between the grips *G1* and *G2*. This included portions of the ends of the test-piece, and he wondered, therefore, whether this had been allowed for when the authors found that there was a great deal of difference in the results as between the short specimens and the long specimens.

As far as results were concerned, he noticed that the authors employed for their record the fourth run on the test-piece. He could not work out exactly how many repetitions that test-piece must have gone through before that, but it would be considerably less than half a million and, of course, not at a constant stress. Did the authors really feel that the number of repetitions had been sufficient to get the material into the cyclic state?

He might be under a misapprehension, but it appeared to him that the same specimen was used for a whole group of tests. For example, in Fig. 4 a comparison was made between the initial stresses to which the specimens were subjected, and actually the four curves, (*a*), (*b*), (*c*) and (*d*), represented one specimen. The previous stress history of the specimen must, he thought, be borne in mind. The same point applied to the elevated temperatures; it appeared as if the same specimen had been used for each whole series of temperatures. Surely the previous stress history of the specimen had some effect on it. Would one obtain the same results if one employed a different specimen for each selected temperature?

The sudden change in shape of the curves for the 0.2% carbon steel at 270° and the 0.9% carbon steel at 310° C. was remarkable. The damping capacity went up from something like 2% to 40% and, moreover, it increased as the stress went down, which was contrary to what he would expect.

Were the authors certain that there was no looseness in the grips holding the specimen? He asked that question owing to the shape of the curve in Fig. 9 when the apparatus was standing on a table and extraneous friction was introduced. A possible explanation might be that there was minute slip within the grains or at the grain boundaries combined with extremely rapid age-hardening within the blue-heat range, but the change was very sudden, and he felt one would see some indication of that earlier.

Mr. T. F. RUSSELL (Sheffield) said his first comment on the paper concerned its title. He suggested that the paper did not deal with "damping capacity" or "its measurement." A more appropriate title might have been "An Investigation of Low-Temperature Abnormalities of Steel from a Study of the Decay of Torsional Vibrations." If it were borne in mind that the paper was limited to that aspect of torsional damping, he thought the discussion

might be confined to the machine and the method of recording the results obtained on it.

A number of people were thinking of building machines for the study of the damping of torsional vibrations, and naturally they would like to know what Professor Thompson's appliance would do before building a similar one.

The authors seemed to be rather concerned about the air resistance, and had said that they had no means of measuring it. They might have put the whole machine in a vacuum and made an actual measurement, or have studied Knackstedt's <sup>1</sup> mathematical treatment of air-resistance losses on a similar type of machine, but what they should not have done, in his opinion, was to decide that the air resistance could not be very much because damping as low as 0.4% had been recorded. He would point out that when the authors got 0.4% damping the torsional strain was of the order of 0.0001, corresponding to a fibre stress of about  $\frac{1}{2}$  ton per sq. in. On the Föppl-Pertz machine there had been recorded an average specific damping of only 0.15% when the torsional strain was 0.003, or the torsional fibre stress about 15.25 tons; the specimen used was a hardened ball-bearing steel.<sup>2</sup> The air resistance, whatever its value, would be greater for a large than for a small amplitude of swing.

Norton <sup>3</sup> also reported that the air damping on his torsion-pendulum instrument, which was of the same type as Professor Thompson's, was of the order of 0.01% at the largest amplitudes used. It was very probable that the air resistance of Professor Thompson's machine was so small that it could safely be ignored.

The authors stated on p. 158 P that Föppl in 1923 defined damping as "the amount of work dissipated as heat by a unit volume of a material during a complete reversed cycle of unit stress." He did not know whether that was Föppl's definition in 1923 or whether it was a bad translation, but it certainly was not Föppl's definition to-day. The second word "unit" should be omitted, because the mean damping depended on the stress cycle.

On p. 159 P was written: "When a material is subjected to a cycle of stress below the 'elastic limit' it is now generally appreciated that a hysteresis loop is obtained." He thought it would be better if the words "elastic limit" were altered to "fatigue limit." It was still a debatable point whether there was any internal damping in a perfectly elastic material—as the authors agreed two sentences later.

The authors stated that they measured their damping capacities by "the natural logarithm of the ratio of any two successive amplitudes of a vibration *the amplitude of which decreases exponen-*

<sup>1</sup> W. Knackstedt, "Die Werkstoffdämpfung bei Drehschwingungen nach dem Dauerprüfverfahren und dem Ausschwingverfahren." Berlin, 1930: N.E.M. Verlag G.m.b.H.

<sup>2</sup> O. Föppl, E. Becker and G. von Heydekampf, "Die Dauerprüfung der Werkstoffe," p. 114. Berlin, 1929: Verlag von Julius Springer.

<sup>3</sup> J. T. Norton, "A Torsion Pendulum Instrument for Measuring Internal Friction," *Review of Scientific Instruments*, 1939, vol. 10, p. 77.



*tially.*" (The italics were his (Mr. Russell's).) If the amplitudes decreased exponentially, then the specific damping ratio, no matter how measured, would remain constant for all stresses. The authors themselves had shown that the specific damping ratio might decrease or increase with fall of stress, so that this statement in italics must be put down to an oversight on their part.

Amongst the factors influencing damping, the authors had omitted pre-stressing. His own opinion was that much of the authors' work was vitiated because the test-piece had not been put in the cyclic condition before being tested. He thought it was wrong to state generally that the damping decreased as the test was repeated. Robertson,<sup>1</sup> writing in 1935, said there was flat contradiction on this point; some workers found that there was an increase, others a decrease of the hysteresis loop caused by repetitions of stress cycles. He (Mr. Russell) thought it was probable that there could be either a decrease or an increase of the hysteresis loop with repetitions of stress, depending on the type of steel and its condition.

There was one point which was noticeable in every curve published by the authors. Fig. 12 might be taken as an example. The initial fibre stress was 19,560 lb. per sq. in., but damping measurements only commenced at a fibre stress of 16,000 lb. per sq. in. Workers in the field of damping would do well to remember that it was the "mean ultimate damping" or the "ultimate surface damping" at which they should aim, and that the nearer the stress cycle approached to the fatigue limit the more valuable the results would be to the engineer. He (Mr. Russell) would therefore be interested to know why the higher initial stresses had been ignored in the authors' reported damping results.

Nowhere in the paper had it been stated that the ordinate was not the "specific damping capacity" but the "mean specific damping capacity." The torsional stress varied from zero at the centre to a maximum at the outside, and it was the mean effect of this range of stress which was determined.

The authors had used twice the logarithmic decrement as a measure of damping, but he thought that this was an undesirable practice. About three years ago he had prepared a short report on various methods of calculating and reporting results from torsional damping tests, and about fifteen copies had been issued to workers who were known to be interested in the subject. The one object of sending out the report was to try to prevent the confusion that might arise through different workers reporting different results from the same set of amplitude readings. He strongly recommended that the mean specific damping ratio,  $\psi$ , should be calculated as  $(a_1^2 - a_2^2)/a_1^2$ , where  $a_1$  and  $a_2$  were the amplitudes of two successive swings.

<sup>1</sup> D. Robertson, "Hysteretic Influences on the Whirling of Rotors," *Proceedings of the Institution of Mechanical Engineers*, 1935, vol. 131, p. 513.

It was quite true that twice the logarithmic decrement gave results sufficiently accurate as long as the mean specific damping ratio did not exceed, say, 5%, but above this figure the discrepancies became appreciable; for example, in Fig. 19 the authors reported a specific damping capacity of about 92%. If he (Mr. Russell) had read the amplitudes in question he would have reported 60%. It would therefore be seen that the matter was an important one.

He would be interested to know what was Professor Thompson's conception of a material having an almost infinite damping capacity. He suggested that the damping to which Professor Thompson was referring should be called 100% damping.

Dr. S. A. MAIN (Sheffield) said that the authors found that carbon steels at about 300° C. became almost "dead," that was to say, they had a very high damping capacity. They quite rightly inferred from their own results that if the amplitude of the vibration was very small the damping capacity might go even higher than the figures that they found at higher stresses. That naturally led to the question as to what would happen in ordinary sound vibrations of a quite mild kind, which might be of only very small amplitude and represent very small stresses. Owing to the implication in the paper that steel became entirely dead at 300° C. when regarded as a tuning-fork, he had carried out a simple experiment with a specimen of carbon steel. He had heated that specimen to about 400° C. and cooled it gradually by stages, and he did not find that at any point the steel did not give a clear and durable ring; there was nothing in the nature of a leady sound or one that was not well sustained. It might nevertheless be that that was consistent with what the authors found. They were concerned with torsional vibrations, whereas his test, he supposed, was concerned with waves of tension and compression, and it might be that that constituted the reason for the difference between the two results. Again, he had carried out his experiment before he knew the full details of the authors' test, and he had used a steel which had only 0.09% of carbon, whereas he noticed in the paper that, although the authors found such a remarkable increase in damping capacity at 300° C. for 0.2% carbon steel and even for 0.9% carbon steel and said that it occurred in all the materials, they did not find that effect in the case of Armco iron, which he supposed had the lowest carbon content of all the materials used. He was sure that many people had seen ordinary carbon steel of all tempers handled in the works at 300° C. or thereabouts without noticing the deadness in it which one would think should be there if the authors' results could be accepted.

He thought the authors were quite right in assuming that the extraneous effects in the tests could only increase the observed coefficient. In the opposite direction, anything inside the steel which increased its damping coefficient also exerted a limitation on the extent to which the coefficient could go. Mr. Russell had

touched on the point that there could not be an infinite coefficient, and that, of course, was obviously not a possibility when one was dealing with a scale of 100%. Extrapolation of the curve in Fig. 22—straightened as far as possible for the purpose by logarithmic plotting—indicated for very small oscillations a coefficient of about 65%.

He asked whether the authors had experienced any unwanted supplementary vibrations on top of the ordinary vibrations, because with the ordinary testing apparatus sold commercially one found very definite oscillations of about 10 times the period of the natural vibration, and they were rather disturbing when one came to make the necessary measurements of the fundamental vibrations.

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### CORRESPONDENCE.

Dr. H. O'NEILL (Derby) wrote that failures in service due to alternating stresses had hitherto been studied largely in relation to fatigue properties, but in recent years damping behaviour had received more consideration. The advantage of a metal with high damping capacity was said to be its greater facility for dissipating applied energy without failure when subjected to cyclic stresses. Thanks were due to the authors for some information upon this subject and for improving the Föppl-Pertz apparatus. It was known that testing technique must be watched very carefully when damping capacity was being studied, and conclusions were very liable to be misleading unless great precautions had been taken.

Without discussing the merits of the apparatus chosen, and considering only temperatures up to about 60° C., the present writer was satisfied that torsional damping increased with an increase of maximum torsional stress, whilst for a given stress it increased with testing temperature, with initial cold-work and with reduction in the carbon content of steel. Qualitatively, at least, the above conclusions were in agreement with the results of previous workers, and, since crystal size had been mentioned, it was also known that damping increased with a decrease of grain size.<sup>1</sup> The results on heat-treated structures were particularly interesting, so that martensite appeared to give high damping and pearlite was somewhat similar, whilst troostite and sorbite had relatively low damping capacities. In this respect it would be an advantage if the authors could give the ordinary mechanical test properties of the steels with which they had experimented.

Regarding the work described at the bottom of p. 191 P, railway engineers were concerned with possible failures of carriage axles,

<sup>1</sup> Canfield, American Physical Society, Dec., 1938. Honda and Konno, *Philosophical Magazine*, 1921, vol. 42, p. 115. Kikuta, *Science Reports of the Tôhoku Imperial University*, 1921, vol. 10, p. 139. Erk, *Zeitschrift für Metallkunde*, 1929, vol. 21, p. 185.

and consideration arose of the relative damping merits of wood, cast-iron and steel wheel centres. Some engineers used normalised steel whilst others preferred axles in the oil-quenched condition. It would be interesting to know whether for equal hardnesses the structure obtained by tempering a martensite differed in damping capacity from that obtained by direct oil-quenching. To the results in this direction so far obtained by the authors, he (Dr. O'Neill) had added the Brinell hardness values shown in Table A.

TABLE A.—*Axle Steel after Various Heat Treatments.*

Analysis : Carbon 0.30%, silicon 0.16%, manganese 0.73%, sulphur 0.030%, phosphorus 0.042%.

Heat Treatment, 1½-in. dia. Bars.	Brinell Hardness.	Specific Damping Capacity at 20–60° C. and Max. Torsional Fibre Stress of 13,000 lb. per sq. in.
Normalised 850° C. . . .	150	2.0%
W.Q. 850° C., T. 675° C. . .	194	2.0%
O.Q. 850° C. . . . .	207	1.3%

The structures of the steels had also been examined, and the oil-quenched specimen was hardly troostitic as described in Table III., but consisted rather of sorbite and ferrite. A material of high damping capacity was said to be less sensitive to the influence of surface notches or sudden changes of section than one of low damping capacity. It was therefore to be inferred that a normalised axle had advantages over one which had been oil-quenched under conditions where fretting and corrosion could occur.

Mr. H. E. SMITH (Teddington, Middlesex) wrote that he would like to congratulate the authors on having overcome the many difficulties in the measurement of damping capacity by the method of decaying torsional oscillations, and also on having presented a series of results which added considerably to the data available for the general discussion of the subject of damping.

He was particularly interested in the remarks on the possibility of materials having a definite damping at extremely low stresses. It might be of interest that a very early worker in this field, W. Voigt,<sup>1</sup> had published, in 1892, some results of tests carried out by the method of decaying oscillations, both in bending and in torsion, which were evidence of this. Corroboration was also given by the work of Förster and Köster published in 1937, who used the resonance of very small electro-magnetically induced bending vibrations.<sup>2</sup>

The effect of overstrain on the damping of a material was also

<sup>1</sup> W. Voigt, *Annalen der Physik*, 1892, vol. 47, p. 671.

<sup>2</sup> Förster and Köster, *Zeitschrift für Metallkunde*, 1937, vol. 29, p. 116.



an interesting point. The authors stated (on p. 165 P and in the Conclusions) that plastic deformation of the material *increased* the damping, and their results certainly showed that a *temporary* increase was caused by overstrain, although the increase seemed to disappear with repeated stressing. Förster and Köster, in the work mentioned above, said that a 0.43% carbon steel, 50% drawn, showed a threefold increase of damping over the normalised material. This was, of course, at the extremely low stress employed in their method. On the other hand, Robertson, in 1935, said that the following was one of the points on which there was general agreement: "The hysteresis of the annealed material is greater (up to eight times has been quoted) than that of the same material hardened by cold-working."<sup>1</sup> Hempel, in the discussion on Föppl's paper in 1936,<sup>2</sup> showed curves demonstrating that the damping of annealed 0.02% carbon steel was greater than that of the same steel after stretching 5% and 10%. The evidence on this point of the influence of overstrain on damping was thus very conflicting, and further information would be of considerable value.

Professor H. WRIGHT BAKER (College of Technology, Manchester) wrote that the authors had placed us in their debt for the very valuable collection of data which they had published, but even more for the admirable exposure of the instrumental errors which might be met by the unwary. The writer, as a mechanical engineer, had been shocked by the deplorable nature of some of the curves which had been published on this subject, and even used for advertising purposes.

In work of the nature of that described, the most perfect elimination of all undesirable degrees of freedom must be sought, and, though the authors had done much to perfect their instrument, it would seem that further refinement was still possible. The double-ended specimen, when properly clamped and freed from temperature stresses, had advantages which should be thoroughly explored before any standard method of testing was adopted.

The frame shown was inherently flexible, on account of the bolted corner joints, and the facts that the upper and lower members of the channel section had little resistance to torsion about horizontal axes, and that the circular balance weight, supported rather undesirably upon a single bolt subject to bending, was carried by a point of the frame where unwanted motion with regard to the clamp was a maximum, instead of in two portions rigidly bolted to the lower corners of the frame. The effect of frame distortion was clearly shown in Fig. 10, while conclusion 2(e) pointed to the existence of parasitic damping. The writer would much like to see comparable tests carried out, using a cast-iron frame having a very high degree

<sup>1</sup> Robertson, *Proceedings of the Institution of Mechanical Engineers*, 1935, vol. 131, p. 513.

<sup>2</sup> Föppl, *Journal of the Iron and Steel Institute*, 1936, No. II., p. 393 P.



of rigidity, as he was convinced that some of the remaining errors, though small, would be further reduced.

Tests had been proceeding in the Mechanical Engineering Department of the University of Manchester, using a double-ended specimen and a heavy cast-iron frame bolted rigidly to a block of concrete weighing about 3 tons. The records, obtained photographically to a scale much larger than that used by the authors, and still further magnified optically before measurement, showed a regularity and consistency of a very high order, but unfortunately tests comparable with those now given were not yet available.

The writer was very glad to have on record the curves of Fig. 8, which revealed clearly the interference effects of various methods of recording. Though the older methods showed up peculiarly badly, as might be expected, the "stylus on celluloid" record was shown to be erratic and hopelessly in error, even compared with the low-magnification optical method now described. After examining many types of record made in this way, the writer was convinced that it had a very restricted field of usefulness, and he wished that, where accurate measurement of rapid movements was required and the driving force was not large, the nail which the authors had driven into its coffin were the last.

Professor P. CHEVENARD (Imphy, Nièvre, France) wrote that the study of the phenomena of internal friction was already of long standing, but it seemed to have preoccupied physicists and chronometer-makers before becoming of interest to metallurgists and constructional engineers. The latter had for long been content with the fundamental hypothesis of the theory of the strength of materials. For all loads below a certain elastic limit, varying with the temperature, it was permissible to regard a commercial metal or alloy as a perfectly elastic solid.

Mechanical hysteresis, though easily demonstrated for loads very much below the elastic limit, was considered to be a phenomenon of too small effect to influence the results of the calculation of the design of machines; further, the dangers in this calculation based on the elastic hypothesis, were reduced by the introduction of large safety factors. The metallurgist therefore abandoned to the physicist the study of mechanical hysteresis, a second-order phenomenon, which seemed to be of the least importance—though not, perhaps, to the chronometer-maker.

Progress in industrial technique forced the practical man to consider matters more closely. In modern machines—light, rapid, hard-driven—certain parts underwent high alternating stresses of high frequency at high temperatures. Further, engineers had learnt, sometimes to their cost, that small phenomena were not necessarily negligible in practice. Hence, in recent years the number of researches on internal friction, also called damping capacity, in metallographic laboratories had multiplied.

As these researches had been more numerous in England, America and Germany than in France and the French-speaking countries, it seemed that the part played by the French school in the study of internal friction, though of long standing and important, might be somewhat unrecognised. In his recent paper, Föppl<sup>1</sup> quoted not a single French-speaking author. The present excellent paper seemed to the writer to present an opportunity to mention a few French researches and to strike a balance of the facts which they had made known concerning the problem of internal friction.

Professor H. Bouasse was certainly one of the first physicists to study methodically and precisely the laws of the mechanical and plastic deformation of metals. While others were preoccupied with the measurement of so-called "constants," such as the elastic modulus, thermo-elastic coefficient, &c., generally measured under small loads, he examined the manner in which these parameters altered under various experimental conditions and when the load, temperature and rate of deformation were varied between very wide limits. His researches were published between 1905 and 1907 in the *Annales de l'Académie des Sciences de Toulouse*, and his conclusions were summarised in successive editions of his "Cours de Mécanique Physique" (Delagrave). The following were the most important relating to internal friction.

Bouasse made an experimental check on Coulomb's hypothesis, which, in the equation for the torsional pendulum, associated with the elastic couple a retarding couple proportional to the velocity, just as though the pendulum were oscillating in a bath of liquid :

$$I \frac{d^2a}{dt^2} + 2b \frac{da}{dt} + Ka = 0.$$

This hypothesis carried three consequences with it : (a) Oscillations which were isochronous, and (b) a decrement which (i) decreased independently of the amplitude and (ii) was inversely proportional to the period. Now experience formally contradicted the two latter; the decrement in the usual metals varied very little with the frequency at low or slightly raised temperatures; it diminished with the amplitude, but it tended towards a finite limit when the amplitude approached zero. The damping of the pendulum in the cold must therefore be caused principally by friction of the solid type; the couple-torsion diagrams were loops pointed at their tops, comparable to magnetic-hysteresis loops; this pointed form was precisely that found experimentally now that one knew how to register the couple-torsion loops by photographic means.

When the temperature was raised, metals passed from the solid-friction to the viscous-friction type, i.e., they became able

<sup>1</sup> O. Föppl, *Journal of the Iron and Steel Institute*, 1936, No. II., p. 393P.

to deform indefinitely in the course of time under a constant load. Some in fact were of this character even at room temperature—for instance, the lead-tin eutectic studied by the Abbé Carrière.<sup>1</sup>

Bouasse analysed the influence of plastic phenomena on the damping of a torsional pendulum. His starting point was a simplified hypothesis of Marcel Brillouin: If, in a wire both elastic and plastic simultaneously, the couple  $C$  were increased by the amount  $dC$  during the time  $dt$ , then the wire experienced a variation  $d\alpha$  in the angle of torsion  $\alpha$ :

$$d\alpha = \frac{dC}{K} + aCdt,$$

the sum of an elastic deformation  $dc/K$  and of a plastic deformation proportional to the couple  $aCdt$ . According to calculation based on such a hypothesis, the decrement was independent of the amplitude and proportional to the period. Bouasse actually demonstrated a decrement that increased with the period in the case of copper at above 300° C. and of the lead-tin eutectic at room temperature; one of the causes of the damping at raised temperature must therefore be plastic relaxation of the couple set up by the torsion.

The researches carried out at Geneva by Guye<sup>2</sup> from 1907 onwards must be mentioned. Well aware of the problems of chronometry from the clock-making traditions of his family, he studied the internal friction as a function of temperature in a number of steels and alloys, among which some ferro-nickels were included. Among the principal results of his work must be mentioned the disagreement between the law of the oscillation of a pendulum and Coulomb's hypothesis; the quasi-independence of the decrement from the frequency at slightly raised temperatures; the diminution of the decrement with the amplitude and the existence of a finite limit for zero amplitude; and the accelerated increase of the decrement as a function of the temperature. The peculiarity of the decrement-temperature curve for steel, characterised by an inflection at about 200° C., should also be noted.

The researches on internal friction undertaken at the Imphy laboratory of the Société de Commentry-Fourchambault et Decazeville dated from 1912. The Imphy steelworks then co-operated with C. E. Guillaume to study the alloy Elinvar; the original purpose of the work was to seek a solution to a problem of chronometry. It was not long, however, before the metallographic aspect took first place. These researches had been described

<sup>1</sup> Z. Carrière, "The Deformation of the Lead-Tin Eutectic Alloy and of Viscous Metals." Thesis. Paris, 1905: Gauthier-Villars.

<sup>2</sup> C. E. Guye and H. Woelfle, *Archives des Sciences Physiques et Naturelles*, July and Aug., 1907.

C. H. Guye, *Journal de Physique*, 1912, p. 620.

in numerous publications,<sup>1</sup> and the following were the most important conclusions :

(1) The decrement of a torsional pendulum was influenced by the least peculiarities in the experimental technique, such as the duration of suspension, &c., and by all the details of the chemical, thermal and mechanical history of the specimen. It was rare to obtain two identical specimens from the same cast and still more so from two different casts, even though they appeared to be similar so far as preparation and chemical composition were concerned. To use Bouasse's expression, internal friction was an "instrument of exquisite sensitivity" for the determination of small differences difficultly appreciated by any other means.

Other things being equal, the internal friction of siderurgical alloys was least in those casts which had been best refined, *i.e.*, the least oxidised, the most easily forged, &c. It was, therefore, a criterion of metallurgical perfection.

(2) In the annealed condition, the decrement,  $\delta$ , of a normal metal or alloy (*i.e.*, free from physico-chemical transformation) varied at first very gently as the temperature,  $\theta$ , was raised; then the increase accelerated and the  $\delta/\theta$  curve rose rapidly. Though, strictly speaking, there was no sharply-defined point of departure of this rapid increase, yet one could speak in practice of a temperature of rapid rise of the decrement.

To a first approximation, the decrement  $\delta$  was the sum of a constant, or, rather, slowly variable, term  $\delta_0$  which represented the solid friction, and of an excess  $\delta - \delta_0$  which increased exponentially with the temperature; in effect, the curve of  $\log(\delta - \delta_0)$  as a function of  $\theta$  was rectilinear to a very close approximation.

(3) This excess  $\delta - \delta_0$  increased with the period, a proof that the temperature of rapid rise of the decrement marked the practical threshold of the phenomena of plastic relaxation. This proof was even quantitative. By calculation based on a hypothesis giving a closer approximation than that of Brillouin, *i.e.*, by assuming that the rate of plastic deformation increased, not proportionally to the couple, but according to an exponential law of the couple, the experimental results were satisfactorily reproduced.

(4) The cold-working of a wire by wire-drawing or by tension augmented the decrement and lowered the temperature of rapid

<sup>1</sup> P. Chevenard, *Comptes Rendus de l'Académie des Sciences de Paris*, 1918, vol. 166, p. 73; 1920, vol. 171, p. 93; 1927, vol. 184, p. 378; vol. 185, p. 1130. *Bulletin de la Société des Ingénieurs Civils de France*, 1923, vol. 76, p. 932. *Travaux et Mémoires du Bureau International des Poids et Mesures*, 1927, vol. 17. *Revue de Métallurgie, Mémoires*, 1928, vol. 25, p. 14. *Proceedings of the American Society for Testing Materials*, 1931, vol. 31, Part I., p. 155.

P. Chevenard and A. Portevin, *Comptes Rendus du Cinquième Congrès de Chimie Industrielle, Paris*, 1926, p. 434.

P. Chevenard, X. Waché and A. Villachon, *Annales de Chronométrie*, 1937, vol. 7, p. 259.



rise. During annealing, the  $\delta/\theta$  curve underwent complicated changes of form, but as a whole it was displaced downwards and towards the right-hand side of the diagram. The cold-working of a carbon steel wire caused Guye's peculiarity to appear, namely, the inflection in the  $\delta/\theta$  curve near  $200^{\circ}$  C.; reheating caused this peculiarity to disappear.

(5) Like all the other physical properties of alloys, internal friction was affected by polymorphic transformations, whether reversible or not. The effect was particularly apparent if the transformation took place below the temperature of rapid rise of the  $\delta/\theta$  curve; thus, the internal friction of the alloy Invar decreased during the magnetic transformation, *i.e.*, while the temperature was rising to the Curie point ( $250^{\circ}$  C.).

(6) Heat treatment had a considerable influence on internal friction. Thus the quenching of a carbon steel increased the decrement, depressed the temperature of rapid rise of the  $\delta/\theta$  curve, and caused Guye's peculiarity to appear, and these effects were still more marked than those of cold-working. The structural hardening of an alloy due to the breakdown of a supersaturated solid solution also increased the internal friction; this increase was related to the appearance of secondary heterogeneity of the resolved solid solution. The quenching of reversible ferro-nickels affected the decrement just as it did the thermo-elastic coefficient, &c.

(7) Documentation had been collected at Imphy on the internal friction of chromium-bearing ferro-nickels and of ferro-nickels to which carbon, chromium, molybdenum, &c., had been added, in a temperature range extending up to  $450^{\circ}$  C. and after various treatments. Those results had been used industrially in developing the chronometric alloys of the Elinvar type.

To summarise, internal friction characterised the elastic hysteresis of solid bodies with an almost limitless sensitivity, because the irreversibility of a couple-torsion cycle, even if it were extremely weak, always became apparent in the long run as a result of the accumulation of the effects of a large number of cycles. The measurement of the decrement was therefore a very fine method of indicating the extent to which a metal or alloy differed from the perfect elastic solid of the theory of the strength of materials, of determining the degree of metallurgical perfection of a product or process, and of elucidating the phenomena of plastic relaxation from the threshold of their manifestation.

For a long time the necessity to use wires had retarded the metallographic application of the method. Nowadays, excellent apparatus, such as that of the authors, was available for measuring the internal friction of a bar cut from the mass. At Imphy an appliance had even been constructed for the testing of micro-test-pieces, which made it possible to explore the anisotropy and heterogeneity of a piece of metal.



In any case, like all integration methods, that of the torsional pendulum gave neither the shape nor the dimensions of the cycle; it furnished only the enclosed area, *i.e.*, the energy transformed into heat by the mechanical hysteresis. It seemed desirable, therefore, to complete the internal-friction tests by registering couple-torsion loops, because it was to be hoped that the detailed analysis of these loops would help towards an understanding of the mechanism of accommodation and fatigue in metals.

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### *AUTHORS' REPLY.*

The AUTHORS replied that, before proceeding to deal with the major points raised by the individual contributors, it might again be worth emphasising that the original reason for this work and the method employed was the investigation of the "low" temperature abnormalities in iron and steel. Further, they would stress the fact that this represented only the beginning of work in a vast field, in which very much more remained to be done. They had explained the technique adopted, the method of calculation used and the results obtained, and so far as these were concerned they had nothing either to add or to subtract.

The authors were gratified that Dr. S. L. Smith agreed that the Föppl-Pertz apparatus in the form in which it had been employed for this work had been considerably improved. They were of the opinion that it now represented a most satisfactory and simple form of apparatus for the measurement of torsional damping, although improvements in detail were still to be expected. They were not satisfied that there was at the moment any evidence to suggest that a method based on direct stress measurements would yield results appreciably different from those in torsion, whilst the apparatus required would be far more complex. If Dr. Smith, however, decided to carry out tests on these lines, they would look forward to the results with the keenest interest. The question of the influence of residual magnetism in the release magnets had been considered in more detail since the paper was first presented. Some comparative tests had been carried out on identical material using, first, the magnetic release, and, secondly, a mechanical release effected by the burning of an inflammable string. The two sets of results fell on an identical curve, indicating that no variation was introduced into the measurements as a result of this cause.

Referring to Dr. Smith's observations on the condition of the material after the fourth run, all that could be said was that in every single case the damping-capacity curves, as measured for the third and fourth runs, were, within the limits of experimental error, identical. The criticism regarding the use of the same specimen for several tests was important. The reason for this procedure, although admittedly not ideal, lay primarily in the fact that the cost of

carefully prepared, separate test-pieces for each of the tests recorded in the present paper would have been of the order of at least £700. More important than this, however, was the fact that the amount of material employed would have been considerable, and the variation in damping properties along even a short bar was by no means small. They had, for instance, found values of  $P$  varying by 50% at points on a single bar only 3 ft. apart.

As some indication of the extent to which the procedure that they had adopted gave results differing from those obtained by direct heating to the temperature, the following figures for  $P$  for a stress of 12,000 lb. per sq. in. might be cited. At 267° C. by the step-by-step method the value of  $P$  was 2.75, by direct heating 2.65. At 285° C. the value in each case was 2.81, whilst at 345° C., *i.e.*, above the reversal temperature, the corresponding figures were 95% and 104%. In view of the very steep slope of the curve in the last case this variation was not excessive. At lower values of stress the variation was rather greater, the figure obtained by the direct method being in all cases rather higher than that obtained after previous tests at lower temperatures.

Taking everything into consideration, therefore, the authors saw no reason to believe that the conclusions reached in the present work were in any appreciable degree less reliable than if each test had been carried out on a new specimen.

Dr. Smith raised the point as to whether the reversal in the curve at a temperature around 300° C. might be due to looseness of the grips. As was pointed out in the paper, the test at each temperature was repeated several times, and it would be surprising if in these tests, and these tests alone, the grips had become loosened. To settle the matter once and for all, however, further tests had been carried out by another investigator on specimens of a mild steel of a slightly different composition, in which the greatest care was taken that such loosening of the grips could not possibly occur. The same reversal of the shape of the curve and the same, relatively sudden, increase in the damping capacity were again observed. There could, therefore, be no question of the results obtained at the highest temperature being due to error of this kind.

With regard to Mr. Russell's contribution the authors might, perhaps, be permitted to say that it seemed to them that he was making rather a fuss about very little. To say that "the paper did not deal with 'damping capacity' or 'its measurement'" was quite wrong. With regard to his remarks about air resistance, the authors saw no reason to modify the wording on p. 195 P of the paper, but they were not disposed to quarrel with Mr. Russell's statement that "it was very probable that the air resistance was so small that it could safely be ignored." With regard to the change in damping capacity on repetition of the test, they saw no reason to alter the statement made in the paper that in no case did the damping capacity increase on repetition of a test and that in the large majority

of instances there was a fall. The authors were just as aware as Mr. Russell that formula (5) on p. 160 p was based on an approximation—they emphasised this in the paper. This approximation, however, introduced no significant difference in any of their results with the exception of the two curves in Figs. 19 and 22 for temperatures above the reversal point, and no modification which had any real meaning even in them. Finally, Mr. Russell's statement that the "work was vitiated because the test-piece had not been put in a cyclic condition before being tested" was unjustified. Work on one subject or branch of a subject was not "vitiated" because it did not deal with something quite different.

Dr. Main's contribution raised the interesting point as to why acoustical and mechanical methods of measuring damping lead to such different results, to which at present there was no satisfactory answer. As the authors had pointed out in the paper, they had expected to obtain around  $120^{\circ}\text{C.}$  values of  $P$  of a very high order, corresponding to Robin's condition of "aphonia"; but this expectation was not realised. The fact that they had confirmed the reversal of the shape of the curve and the very high values of  $P$  about  $300^{\circ}\text{C.}$ , not found acoustically by Dr. Main, was another instance of this difference. With regard to the question of unwanted, supplementary vibrations superposed on the original oscillation, a large number of the authors' curves had been re-examined and nothing of this nature was to be observed in any of them.

Dr. O'Neill's interesting contribution raised no points which needed discussion here.

The authors especially welcomed the remarks of Mr. H. E. Smith. In connection with the results of Förster and Köster and the much greater effect due to cold-work which they had observed, this was probably to be ascribed to the greater severity with which their own material was deformed. In none of the authors' experiments had they ever found a decrease in damping due to cold-work, though ageing effects might lead to an apparent change in this direction.

The observations of Professor Wright Baker regarding the construction of the apparatus appeared to the authors to be justified. If they were to redesign this with their present experience a heavy cast-iron frame might be employed, but the high damping capacity of some grey irons was a somewhat serious objection to the use of this material. They had no reason, however, to believe that the bolting of the frame to a concrete block would in any material way modify the results obtained with the type of suspension here employed.

The authors welcomed very heartily the observations of Professor Chevenard, to whose work reference had already been made in the paper itself. They apologised if they had given the impression that they were unappreciative of French contributions to the study of damping, but they did plead guilty to not having realised how great these actually were. Professor Chevenard's most excellent summary

added greatly, therefore, to any value which the paper itself might have. They would like to express their gratitude for the kind terms in which Professor Chevenard referred to their own work and again to assure him, and all French-speaking readers of the paper, that French contributions to this field of study were now appreciated at their true, high worth.

The work was being continued under another investigator; certain of the points of criticism were receiving further attention, but nothing which had so far emerged gave the authors any reason to doubt the validity of the conclusions previously reached.



# REPORT ON CORROSION RESEARCH WORK AT CAMBRIDGE UNIVERSITY INTER- RUPTED BY THE OUTBREAK OF WAR.<sup>1</sup>

BY U. R. EVANS, Sc.D. (CAMBRIDGE UNIVERSITY).

*Paper No. 1/1940 of the Corrosion Committee.*

## SUMMARY.

A description is given of researches by a group of investigators interrupted by the war; the results obtained up to September, 1939, are summarised, and interpretations—necessarily tentative—are suggested.

Agar's exploration of the potential distribution close to the surface of zinc partly immersed in chloride or sulphate solution showed definitely that electric currents were passing between a cathodic zone, situated in the well-aerated region at the meniscus, and an anodic zone below it. Visible corrosion was always associated with the zone which the electrical apparatus showed to be anodic. From the distance between equipotential lines, the strength of the currents could be calculated. It was found that these were strong enough to account for at least the *greater part* of the corrosion—and probably for the whole of the corrosion leading to *loose* corrosion product (the small amount of adherent corrosion product has a different origin). The researches had not proceeded far enough to ascertain whether there was an *exact* equivalence between current strength and corrosion rate, but they have established the fact that the attack is at least mainly electrochemical.

A convenient criterion of the protective character of a film is the amount of acid which must be added to copper nitrate to cause deposition of copper when a drop is placed on an iron surface. The author's comparative tests on heat-tinted and other specimens of carbonyl iron have confirmed the belief that iron carrying interlocked oxide is better protected than iron carrying somewhat thicker films, where the interlocking is less. The tracing of a scratch-line with a weighted needle on tinted iron did not, in general, perceptibly increase the susceptibility to attack, provided that there was a short exposure to air before the placing of the drop on the surface. But specimens which had been kept two years in a desiccator after tinting showed a significant increase of susceptibility when freshly scratched.

Mayne's attempts to obtain, by means of water-emulsification, a rust-inhibitive priming paint suitable for application (a) to steel wet with water, and (b) to steel partly weathered so as to carry broken scale, rust and iron salts, appear to have succeeded, so far as objective (a) is concerned, although prolonged outdoor tests will be needed before definite claims can be made. At the time of the outbreak of war, objective (b) had not been attained.

Gould's work on corrosion-fatigue, of which an account had been published early in 1939, was continued up to the outbreak of war; the chief new results concerned the prevention of corrosion-fatigue by

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<sup>1</sup> Received November 3, 1939.



means of zinc ribbon, even in cases where the steel surface was not completely covered up. This was effective in the case of chloride solutions, but less so in the case of typical tap water, owing to its lower electrical conductivity.

Hoar's results on the influence of the steel base on the corrosion of tin cans containing fruit were also published in 1939; this work is still being continued.

Price and Thomas' work on the tarnishing of silver has been terminated.

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THE outbreak of hostilities in September, 1939, has unfortunately caused the abandonment of much of the research into corrosion which had been proceeding at Cambridge University through the kind support of the Corrosion Committee and the Alloy Steels Research Committee of the Iron and Steel Institute and the British Iron and Steel Federation. It is thought desirable to set forth the conclusions reached tentatively at the time of this abandonment, although on some points the opinions must be put forward with reserve, since, in the ordinary course of events, further research would have been carried out before any publication was made.

#### RESEARCHES INTO THE ELECTROCHEMICAL CHARACTER OF CORROSION.

Researches had been proceeding for some years to ascertain whether the electric currents which were already known to flow over the surface of corroding metal, were strong enough to account for the whole of the corrosion actually observed or only for part of it. In 1938, R. S. Thornhill <sup>1</sup> had found that the electric currents flowing around a scratch-line on iron wetted with sodium bicarbonate solution were capable of causing the greater part, and probably the whole, of the corrosion produced. But the application of Faraday's law, in correlating current strength and corrosion rate, was complicated by the fact that iron has two electrochemical equivalents (according to whether it dissolves in the ferrous or ferric state). It was, therefore, decided to continue the work on zinc, which has only one electrochemical equivalent, and thus obtain a more definite answer to the question as to whether such cases of corrosion were wholly or only partly electrochemical. Since the corrosion phenomena on zinc and iron are closely analogous to one another, it was probable that any conclusions reached in the case of zinc would be valid in the case of iron.

Accordingly, Thornhill <sup>2</sup> constructed a special form of di-electrode, which served to detect anodic and cathodic areas on corroding metal, giving a deflection in different directions according as it was brought against a cathodic or anodic point. Studying the case of a zinc specimen partly immersed in dilute ( $N/1000$ ) sodium

<sup>1</sup> R. S. Thornhill and U. R. Evans, *Journal of the Chemical Society*, 1938, p. 614.

<sup>2</sup> R. S. Thornhill and U. R. Evans, *Journal of the Chemical Society*, 1938, p. 2109.

chloride solution, he found that the points which the electrical apparatus showed to be anodic always suffered visible corrosion, whilst those which were found to be cathodic or neutral in the electrical sense always remained free from attack; places which the electrical apparatus showed to be temporarily anodic suffered only temporary corrosion. These observations strongly suggested that, in such cases, the corrosion was wholly of an electrochemical character, but it seemed important to measure the currents flowing and then to

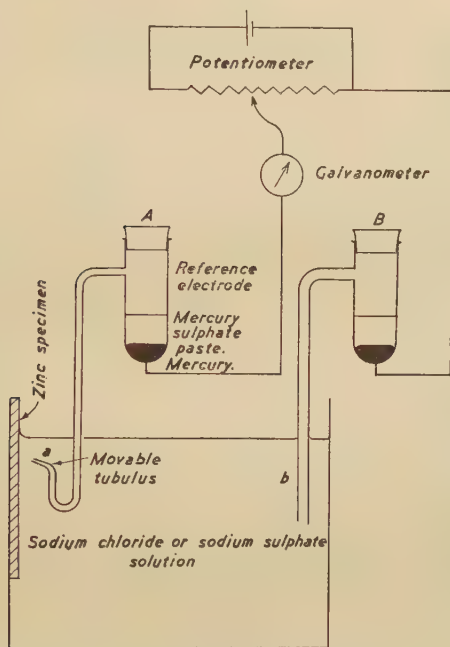


FIG. 1.—Apparatus for Exploring the Distribution of Potential around Corroding Zinc.

apply Faraday's law, so as to ascertain whether the currents were sufficiently strong to account for the whole of the corrosion observed.

Such experiments were being carried out by J. N. Agar when war broke out. The method was to explore the distribution of potential in the solution (sodium chloride or sulphate) around a corroding zinc strip by means of a tubulus leading to a reference electrode *A* (Fig. 1). The tubulus, *a*, could be moved in three directions at right angles. Another, exactly similar, reference electrode, *B*, was connected to a *fixed* point in the solution by the tube *b*. For the experiments in chloride solutions Ag–AgCl electrodes were used, while in sulphate solutions Hg–Hg<sub>2</sub>SO<sub>4</sub> electrodes

were employed. The solution in the tubulus and electrodes was of the same concentration as the corroding liquid. The two electrodes were connected to a potentiometer and galvanometer. The potentiometer was set to some predetermined value (say,  $50 \times 10^{-5}$  V.) and the tubulus and electrode *A* were moved until the galvanometer deflection was reduced to zero. A series of positions fulfilling this condition can be found; in all such positions the point in the liquid occupied by the tip of the tubulus must have the same potential.

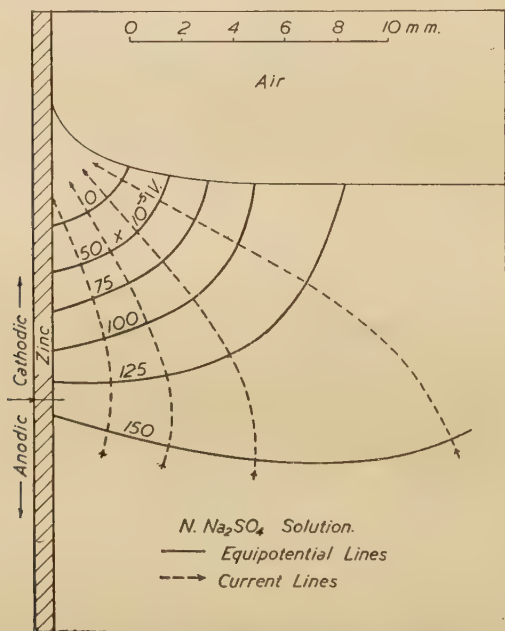


FIG. 2.—Potential Distribution and Current Flow around Zinc Corroding in Normal Sodium Sulphate Solution.

This procedure can be repeated with a different setting of the potentiometer, and in this way a series of *equipotential curves* can be traced. Of these, the curves shown in Figs. 2 and 3, which refer to normal sodium sulphate and normal sodium chloride respectively, are typical. The flow of the electric current is, of course, always at right angles to the equipotential lines, and in all cases the curves indicate that the cathodic region is the well-aerated part in the meniscus and that the anodic region lies below it; in other words, the only electric currents which could be detected were of the differential-aeration type. The vertical distance between the centres of the

anodic and cathodic areas varied from one specimen to another and with time, but was on the average greater in sulphate solutions than in chloride solutions, and was also greater in concentrated than in dilute chloride solutions, as would be expected. The general distribution of anodic and cathodic areas remained the same after 14 days, and the zone shown to be anodic by the electrical measurements coincided with the zone visibly attacked, thus confirming Thornhill's experiments.

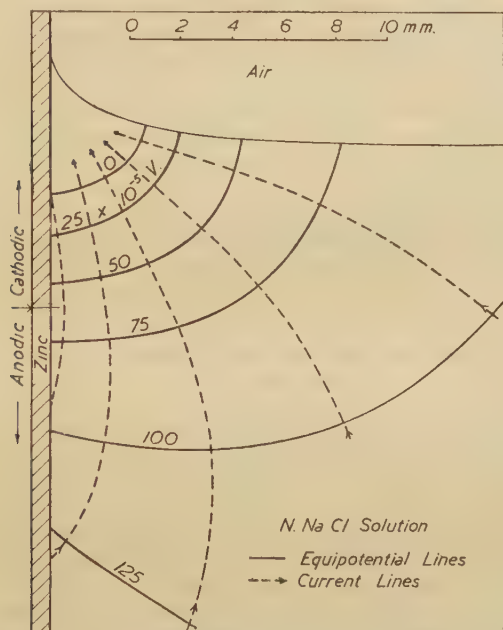


FIG. 3.—Potential Distribution and Current Flow around Zinc Corroding in Normal Sodium Chloride Solution.

The equipotential *lines* obtained by this method, and shown in Figs. 2 and 3, really represent the section of a set of equipotential *surfaces* cut by a vertical plane at right angles to the surface of the corroding specimen. If two such equipotential surfaces differ in potential by  $\Delta V$  volts and are separated by a distance  $n$ , the current flowing from one to the other is approximately  $\kappa A \Delta V / n$ , where  $\kappa$  is the specific conductivity of the liquid and  $A$  the area of the two surfaces. If we now consider equipotential surfaces extending for 1 cm. in the direction of the water-line, it is clear that the area of any such surface is equal to  $\sigma$  sq. cm. where  $\sigma$  is the *length* of the equipotential lines, such as those shown in Figs. 2 and 3. From

two such lines, separated by a mean distance  $\bar{n}$  and having lengths  $\sigma_1$  and  $\sigma_2$ , we can thus calculate  $j$ , the current per centimetre length of water-line, from the expression :

$$j = \kappa \left( \frac{\sigma_1 + \sigma_2}{2} \right) \frac{\Delta V}{\bar{n}}.$$

Although the work had not been completed at the moment of the outbreak of war, it is already possible to state that the electric currents thus measured are strong enough to account for the greater part of the corrosion actually observed, and probably correspond to the whole of the production of the loose corrosion product. A small amount of highly adherent corrosion product formed above the water-line has clearly a different mode of origin. It may be due to electric currents travelling over paths too short to be detected on the apparatus in question. But it is more likely to be connected with the upward creepage of sodium hydroxide which is formed as the cathodic product at the water-line.

These three researches (of which two have actually been published, and one has been left unfinished) show that the cases of corrosion studied are mainly, and probably wholly, of an electrochemical character.<sup>1</sup>

#### EFFECT OF A SCRATCH-LINE ON THE PROTECTIVE CHARACTER OF SUPERFICIAL OXIDE.

In a recent research on passivity towards natural waters,<sup>2</sup> it was noticed that the protection afforded by certain treatments in chloride and chromate was not seriously affected if a scratch-line was subsequently made on the surface. It was subsequently shown that Cambridge water treated with sufficient chromate to make it non-corrosive to steel under stagnant conditions, remained non-corrosive even if the surface was scratched continuously with a weighted needle. These observations rather suggest that the protective layer produced by the chromate is in effect malleable. Some indications of the malleable character of the mixture of oxide and metal formed near the surface after mild superficial oxidation was obtained during work on the transfer of oxide from iron to celluloid<sup>3</sup>; it was found that the relatively thick films responsible for the late interference colours were cracked off bodily when a scratch-line was made on the surface, only isolated fragments being pushed into the metal, but some evidence was obtained that

<sup>1</sup> This refers to *stagnant* solutions. It remains possible that under conditions of great agitation (where the product of direct oxidation might be continuously removed as it is formed, so that the direct oxidation will not be smothered) corrosion may be produced in a way which involves no passage of electric currents over paths of appreciable length.

<sup>2</sup> U. R. Evans, *Nature*, 1938, vol. 142, p. 160.

<sup>3</sup> U. R. Evans, Fifth Report of the Corrosion Committee, p. 239, *Iron and Steel Institute*, 1938, *Special Report No. 21*.



the oxide formed on more gentle heating was pushed down bodily into the metal when a scratch-line was made. On iron heated to develop the first straw-yellow interference colour, there seems to exist below the oxide film proper a mixed zone of metal and oxide, as shown in the early work with J. Stockdale<sup>1</sup>; the intimately mingled character of the superficial oxide and metal produced when iron is abraded at ordinary temperatures is well brought out in the recent work of Vernon, Wormwell and Nurse.<sup>2</sup>

It seemed highly important to ascertain whether, in the case of films formed by simple oxidation in air, scratching caused appreciable loss of protective character. Early work on this point had suggested that breakdown of passivity usually occurred when the scratching point was of a jagged character, but that scratching with a simple point had relatively little action.<sup>3</sup> It was decided to use acidified copper nitrate solution as a test for the protective character of the film, since the action of such a solution depends largely on the acid content. A concentrated solution of copper nitrate without free acid usually renders iron passive under conditions where an acidified solution causes immediate deposition of copper. The amount of acid needed to cause the precipitation of copper forms a convenient measure of the protective character of a given film. In the present work copper nitrate solution was made by shaking normal nitric acid with excess of copper carbonate, then filtering without boiling off the carbon dioxide, and adding a definite small amount of free normal nitric acid. The amount of acid needed to produce copper deposition was adopted as an index of the efficiency with which an oxide-containing layer helps to protect the metal.

It was found that the foreign substances left on iron when abraded with Hubert emery paper apparently favour the deposition of copper, and it was necessary to clean all specimens in vapour. The cleaning of thin sheet in an ordinary form of vapour degreaser is apt to be ineffective, since as soon as the sheet reaches the boiling point of the liquid, condensation ceases. A simple device was arranged whereby the metal to be cleaned was joined to a large air-cooled surface outside the vessel, so that condensation continued indefinitely, rendering progressive cleaning possible (Fig. 4). The vessel is covered with a mica plate, slotted to admit the specimen.

By heating a strip of carbonyl iron at one end so as to produce the usual sequence of interference colours, and applying rows of drops of copper nitrate, each row containing a different amount of free acid, the author has prepared charts, of which Fig. 5 is typical. Altogether 68 of such charts have been prepared, comprising the study of about 3000 drops; certain "regions" call for much fuller

<sup>1</sup> U. R. Evans and J. Stockdale, *Journal of the Chemical Society*, 1929, p. 2651.

<sup>2</sup> W. H. J. Vernon, F. Wormwell and T. J. Nurse, *Journal of the Chemical Society*, 1939, p. 621.

<sup>3</sup> U. R. Evans, *Journal of the Chemical Society*, 1929, p. 99.

exploration, but several facts have been definitely established. All the specimens showed that much more acid is needed to produce

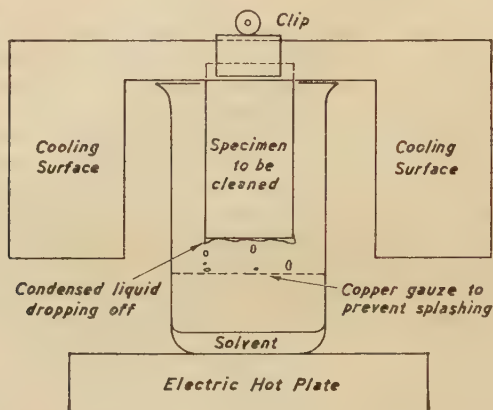


FIG. 4.—Simple Apparatus for the Vapour-Cleaning of Thin Sheet.

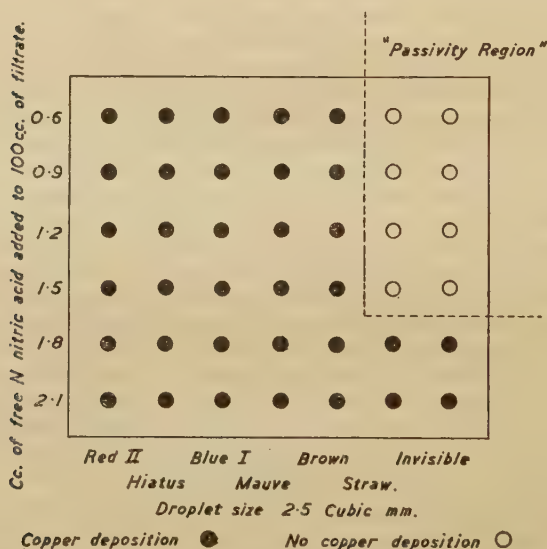


FIG. 5.—Effect of Copper Nitrate Drops on Heat-Tinted Iron.

copper deposition in the faintly straw-coloured region and the adjoining region which has suffered no visible change, than in the

region represented by definite interference colours. This confirms early results<sup>1</sup> which showed that the amount of oxide capable of producing definite interference colours afforded less protection than the amount of oxide just insufficient or barely sufficient to give interference colours. The more protective type of oxide corresponds to the conditions where the oxide is so much interlocked with the metal that it does not develop cracks through accidental bending or internal stresses in the metal.

The most interesting point was brought out by the study of specimens on which scratch-lines had been engraved, in the Mears-Ward machine,<sup>2</sup> just before the drops were placed in position. Comparison with experiments on unscratched specimens carried out under otherwise identical conditions showed that under many circumstances *scratching did not appreciably increase the liability to the deposition of copper*, although the distribution of attack was altered; in regions covered with interference colours, there was a tendency for the copper to be deposited along the scratch-line, whereas in the absence of a scratch-line it would be deposited at isolated points below the drop, doubtless representing accidental cracks in the film. In the neighbourhood covered by very thick films, the state of affairs is complicated by the presence of a magnetite film below the ferric oxide film and by the fact that copper deposition, if it occurs, is not always very conspicuous; it is preferred to make no statement about this region at present. With regard to the regions covered with early interference colours and those which have acquired no tints, it may be stated definitely that scratching does not seriously increase the tendency for the deposition of copper, provided that the drop is not applied immediately after scratching.

The observed facts receive an explanation when it is remembered that passivity towards any solution does not require a continuous oxide sheath, but that the metal becomes passive when the ratio of bare metal to oxide-covered area falls below a certain value, which depends upon the nature of the solution employed. In the case of copper nitrate the critical ratio is probably higher than in most solutions. When iron covered with a discontinuous sheath of oxide is placed in a copper salt solution, copper is likely to be deposited on the oxide sheath as cathode, whilst iron will go into solution as an iron salt at the bare portions, which are anodic. This action will, however, cease almost at once if the bare portions are so small that the anodic current density exceeds the passivating value, and in a nitrate solution this critical current density is low, so that relatively large bare areas are consistent with passivity. On abraded iron which has not been intentionally heated, the metal and oxide are

<sup>1</sup> U. R. Evans, *Journal of the Chemical Society*, 1937, p. 1028. For the corresponding observations on copper, see U. R. Evans, *Journal of the Chemical Society*, 1925, p. 2191; compare also the results of W. H. J. Vernon, *Journal of the Chemical Society*, 1926, p. 2273.

<sup>2</sup> R. B. Mears and E. D. Ward, *Journal of the Society of Chemical Industry*, 1934, vol. 53, p. 382r.

intermingled in a confused fashion (Fig. 6 (a)); here the deposition of copper at the edges of the particles will itself reduce the area of bare metal (Fig. 6 (b)), so that even after copper deposition has begun, passivity may set in later, after a certain amount of copper has been deposited. Cases were noted under border-line conditions between the active and passive regions where, although no typical copper deposition took place, a just perceptible very rapid darkening was observed about a second after the drop was placed in position. If a surface consisting of a confused mixture of oxide and metal is scratched, the operation will still leave a confused mixture of oxide and metal in the groove produced, and the ratio of bare surface to oxide may not be greatly increased by the engraving of a scratch-line on the surface, especially if there is exposure to air between

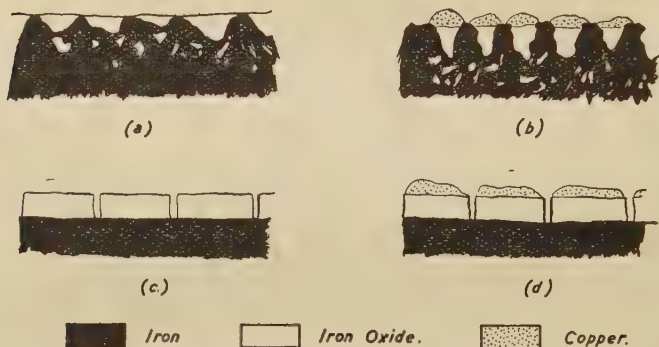


FIG. 6.—Diagrammatic Representation of the Probable Effect of Copper Nitrate on Superficially Oxidised Iron. (a), (b) interlocked oxide; (c), (d) massive cracked oxide. (a), (c) before application of copper nitrate; (b), (d) after application of copper nitrate.

scratching and the application of the drop. This explains why scratching does not greatly alter the acidity needed for copper deposition on metal heated insufficiently to produce interference tints. In the case of somewhat more strongly heated metal, carrying interference colour films, it is clear that scratching will crack off the film and produce a definite groove, but films of this sort are themselves apt to contain cracks (even where no scratch has been made through them), and thus in these cases also, scratching makes no serious difference to the degree of protection. Exposure to dry air after tinting increases the tendency to passivity. A series of uniformly tinted specimens prepared by H. A. Miley early in 1937, and stored in a desiccator until July, 1939, showed a very small tendency to copper deposition whether the drops were applied (a) at places where no scratches had been made, (b) on scratches made two years previously, or (c) on scratches made two days previously.



Where scratches were made 5–15 sec. before the application of the drop, the tendency to deposit copper was definitely greater.

The greater effect of a jagged scratch in dispelling passivity is probably due to the fact that it will leave not only dents in the metal but also tensional stresses which will tend to keep cracking any film which may be formed by the passivating agent.

It is likely that the special susceptibility to attack upon metal covered with massive oxide films capable of producing interference colours (Fig. 6 (c)) is due to the fact that much of the copper produced by cathodic action on such a surface will be deposited on the cliffs of massive oxide far away from the exposed metal (Fig. 6 (d)). Thus there is a far smaller tendency for the copper deposition itself to reduce the size of the bare-iron areas than in the case of less strongly heated iron carrying invisible oxide mixed up in a confused fashion with the metal (Fig. 6, (a) and (b)).

Although the action of copper nitrate on partly oxide-covered iron differs from that of ordinary waters, in that the cathodic product is metallic copper instead of some body (calcium carbonate or sodium hydroxide, in hard and saline waters respectively) which can subsequently interact with the iron salts formed at the anode, yet the conclusions reached above may be helpful in showing why (especially on stainless steels) massive visible oxide is frequently an accelerator, or at least a local intensifier, of corrosion, whereas invisible oxide, especially if so much interlocked as not to be cracked off on bending, plays a protective rôle.

#### DEVELOPMENT OF PAINT FOR APPLICATION TO STEELWORK IN UNFAVOURABLE SURFACE CONDITIONS.

The extensive results obtained by J. C. Hudson for the Corrosion Committee and also several series of tests conducted by the Cambridge Group<sup>1</sup> (including the recently terminated seven-year tests) have indicated that admirable protection can be obtained over long periods even in severely polluted atmospheres, provided that inhibitive paint, followed by two suitable coats chosen for their mechanical properties, has been applied to a surface free from moisture, scale, rust and salt. But, if the steel is damp at the time of application, it is well known that good results cannot be obtained and that even an invisible film of moisture reduces the protection; in one set of tests at Cambridge, specimens painted in the early morning gave results definitely inferior to those painted in the afternoon with corresponding paints. Far worse is the presence of broken mill-scale on the metal. In the tests carried out by K. G. Lewis<sup>2</sup> at Cambridge, the worst results were obtained when

<sup>1</sup> S. C. Britton and U. R. Evans, *Journal of the Society of Chemical Industry*, 1930, vol. 49, p. 173T; 1932, vol. 51, p. 211T; 1936, vol. 55, p. 337T; 1939, vol. 58, p. 90.

<sup>2</sup> K. G. Lewis and U. R. Evans, Third Report of the Corrosion Committee, p. 173, *Iron and Steel Institute*, 1935, *Special Report No. 8*.



steelwork had been allowed to weather before painting for a sufficient period to produce small holes in the covering of mill-scale; this appeared to be an example of the intense corrosion always set up where a large cathodic area (the part covered with mill-scale) is associated with a small anodic area (the breaks in the mill-scale), as indicated in Fig. 7. The non-adherent mill-scale and most of the rust present on weathered steel can be removed by wire-brushing, but the ordinary wire-brush leaves the whole of the adherent mill-scale and even a small amount of rust in microscopic "blobs"; if produced in a polluted atmosphere this residual rust will generally contain soluble salts of iron.

Since in practice steelwork may have to be painted under unfavourable weather conditions and since the removal of scale and rust by pickling or sand-blasting is not always an economical process, it is of vital interest to develop paints which can be applied to surfaces which are (a) wet with water, (b) partly covered with

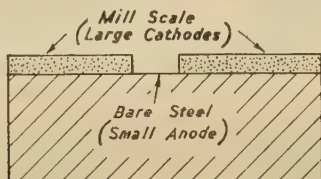


FIG. 7.—Cause of Intensified Corrosion at Breaks in Mill Scale.

mill-scale, or (c) carrying the residual rust left after wire-brushing. Water-emulsion paints capable of being applied to wet steel are made at present, but these are mostly bituminous paints. They have given good results in Swiss tests.<sup>1</sup> It seemed important to develop a typical inhibitive oil paint dispersed in an aqueous medium for application in wet weather. The first attempts at Cambridge led to paints of unstable properties or otherwise unsuitable technical character. J. E. O. Mayne has now examined emulsion paints pigmented with red lead and metallic zinc, which, when applied to steelwork fully wet with water, give good coats.<sup>2</sup>

The question of painting steel partially covered with scale and rust residue is a more complicated problem. Attempts have been made, especially in America, to develop inhibitive washes<sup>3</sup> which, it was hoped, would bring weathered steelwork to a state suitable for painting. There seems some little doubt, however, whether these

<sup>1</sup> A. V. Blom, *Schweizerischer Elektrotechnischer Verein*, 1934, *Bulletin* No. 14.

<sup>2</sup> The composition of Dr. Mayne's paints is known to the author, but publication at the moment would be premature.

<sup>3</sup> See Fifth Report of the Corrosion Committee, p. 354, *Iron and Steel Institute*, 1938, *Special Report* No. 21.

washes in all cases fulfil the claims made for them, and the opinion in America is veering round to the view that the removal of scale and rust by pickling or sand-blasting is still necessary, even if inhibitive washes are used.

It seemed possible that, if soluble inhibitive substances, such as potassium chromate, were introduced into the aqueous dispersion medium of emulsified paint, the necessary inhibition of the corrosion couples present on partly descaled metal might be obtained during the application of these emulsified paints, thus avoiding the additional process (the application of the inhibitive wash). The first attempts at Cambridge to introduce soluble chromates into the emulsified paint led to instability of the emulsion, but this difficulty was subsequently overcome by Mayne by adjustment of the composition. However, it was found that the presence of potassium chromate caused rapid development of fresh rust at the points where the microscopic rust particles left after wire-brushing existed. This rapidly caused the pushing away of the paint film in microscopic

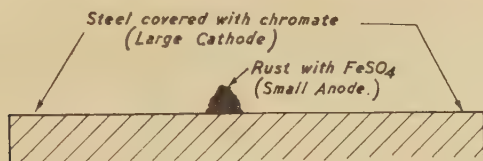


FIG. 8.—Cause of Intensified Corrosion at Particles of Residual Rust.

pimples during the drying. The rapid rust production at points where rust residues exist on a weathered steel surface could be brought about by potassium chromate solutions in the absence of paint, and a study of the matter suggested that it was due to residues of iron salts, probably ferrous sulphate, in the rust particles. This combination gave rise to the cell:

Iron/ferrous-sulphate/potassium-chromate/iron,

as suggested in Fig. 8. Since here again there was a small anode and large cathode, the attack was locally very intense. Accordingly it was decided to abandon the use of soluble chromates and indeed of such slightly soluble pigments as zinc chromate. It seemed possible that the same beneficial effects as had been sought through the use of soluble inhibitors might be obtained by using an emulsion paint containing metallic zinc pigment, which would send local currents in the opposite direction and might perhaps overcome the effect of the cell iron/mill-scale, without the use of inhibitive washes or soluble inhibitors in the paints.

Accordingly Mayne exposed on June 19, 1939, some preliminary specimens coated with emulsified metallic zinc paints and emulsified red lead paints. Certain portions of each specimen were coated

with ordinary iron-oxide oil paint over the emulsified primer, whilst another portion of each carried iron-oxide paint alone. These specimens were exposed to the Cambridge atmosphere, but the rising of the paint has not been prevented in cases where mill-scale was present; scale-free specimens, even though painted when wet with water, were behaving well after three months' exposure. Although some years must elapse before a definite decision can be given, it would seem probable that the problem of painting wet metal has been solved, but that the problem of painting partly weathered metal has not been solved. The specimens exposed in these outdoor tests carried emulsion paints of a relatively preliminary composition. Subsequent to the starting of these exposure tests, considerable improvement has been effected in the composition of the various emulsion paints, but, owing to the war, it has not been possible to start fresh exposure tests with the improved paints. If circumstances should permit, it may be possible to start these additional exposure tests later.

#### INVESTIGATION OF CORROSION-FATIGUE.

The work carried out by A. J. Gould and financed by the Alloy Steels Research Committee was fully reported in 1939.<sup>1</sup> Since that time attention has been paid to the prevention of corrosion-fatigue by means of zinc. Zinc ribbon wound loosely round iron wire greatly increases the corrosion-fatigue life in chloride solutions, even when the access of the corrosive agent to the metal is not prevented. This is clearly due to cathodic protection, since experiments, kindly suggested by J. C. Hudson, have shown that an iron ribbon used in the same way does not improve the life. Unfortunately, owing to the low electrical conductivity of typical tap water, very little protection is given by loosely wound zinc ribbon to iron wetted with such water, and it is evident that the apertures in the zinc covering must, in such cases, be made much smaller, if protection is to be obtained. Possibly the metallic zinc paints now being developed by J. E. O. Mayne may prove useful in preventing corrosion-fatigue, even in cases where, for technical reasons, the actual point of breakdown cannot be coated with the paint. It had been intended to carry out further work on these lines, but here again the outbreak of war has put a stop to the work.

#### CORROSION-RESISTANCE OF TINPLATE AS USED IN CANNING.

The extensive series of tests with actual fruits canned in tins made from steels of different compositions was fully reported up to a recent date,<sup>2</sup> the first results being concerned with lacquered-can

<sup>1</sup> Second Report of the Alloy Steels Research Committee, p. 325, *Iron and Steel Institute*, 1939, *Special Report No. 24*.

<sup>2</sup> T. P. Hoar, T. N. Morris and W. B. Adam, *Journal of the Iron and Steel Institute*, 1939, No. II., p. 55 P.

packs of typical fruits. A copper content in the steel up to 0.2% was shown to be usually beneficial, while in certain cases a minimal phosphorus content is beneficial. Laboratory corrosion tests made on the steels were found to give considerable indication of the behaviour of the cans in practice. Further similar work on plain-can packs is now being completed. The subject under study is of considerable economic importance at the present time and it is hoped to be able to continue the research, especially in regard to the structure of the steel base; the work is being carried on by T. P. Hoar in the Corrosion Laboratory in conjunction with T. N. Morris of the Low-Temperature Research Station and W. B. Adam of the Fruit and Vegetable Preservation Research Station, Chipping Camden.

### PREVENTION OF TARNISHING OF SILVER.

The work of Price and Thomas on the tarnishing of silver has been carried further, and two more papers have been recently published.<sup>1</sup> The new results are concerned mainly with the optimum conditions for the electrolytic production of an invisible protective film of alumina or beryllia on the silver, and with methods for the estimation of the minute quantities of tarnish products present on silver and copper alloys. The electrometric principle formerly used at Cambridge by L. C. Bannister for the estimation of silver-iodide films<sup>2</sup> and subsequently developed by H. A. Miley for the estimation of oxide films on iron and copper<sup>3</sup> has been employed. Price and Thomas found that the amount of tarnish measured electrometrically agrees well with the gain in weight produced during tarnishing and the loss of weight produced during de-tarnishing. This agreement indicates that in suitable conditions the electrometric method of film estimation may be very valuable. It may be added that it is possible to detect and roughly to estimate four different corrosion products which are present in minute traces in the tarnish film produced when sterling silver is exposed to a tarnishing atmosphere. These are silver sulphate, silver sulphide, cuprous oxide and cuprous sulphide; by ordinary chemical methods the simultaneous detection and estimation of these bodies would be practically impossible.

### ACKNOWLEDGMENTS.

The author wishes to make it clear that, with the exception of the research on the effect of a scratch-line on surface films, the whole

<sup>1</sup> L. E. Price and G. J. Thomas, *Journal of the Institute of Metals*, 1938, vol. 63, p. 29; 1939, vol. 65, p. 379; *Transactions of the Electrochemical Society*, 1939, vol. 76, p. 329.

<sup>2</sup> U. R. Evans and L. C. Bannister, *Proceedings of the Royal Society*, 1929, A, vol. 125, p. 370.

<sup>3</sup> U. R. Evans and H. A. Miley, *Nature*, 1937, vol. 139, p. 283. H. A. Miley, *Iron and Steel Institute, Carnegie Scholarship Memoirs*, 1936, vol. 25, p. 197.



of the experimental work recorded in this paper was carried out by his collaborators, not by himself; he also wishes to acknowledge their help for useful discussion regarding the writing-up of this paper—particularly he would mention in this connection the assistance of Dr. A. J. Gould, Dr. T. P. Hoar, Dr. J. E. O. Mayne and Dr. J. N. Agar.

The work in the Cambridge Corrosion Laboratory has been made possible through the generous financial assistance of the Iron and Steel Research Council acting through the Corrosion and the Alloy Steels Research Joint Committees of the Iron and Steel Institute and the British Iron and Steel Federation. The author wishes to acknowledge the kind interest of the members of these committees, and particularly the support and kindly advice afforded at all times by the Chairman, Dr. W. H. Hatfield, F.R.S.



*DISCUSSION.*

Dr. G. D. BENGOUGH, F.R.S. (Teddington, Middlesex), in opening the discussion, said that in some ways the paper was difficult to discuss, because, as the author said, most of the researches referred to were in an initial or only a moderately advanced stage. The paper contained accounts of six researches, three of which had to do very largely with theoretical matters of great academic interest and three of which were concerned with matters of more immediate industrial interest.

So far as the theoretical papers were concerned, he was particularly interested in Dr. Agar's work. In the conditions described in the paper, he had very little doubt that Dr. Agar's conclusion that the currents measured closely represented the amount of corrosion that had taken place was correct, but he would prefer to re-draft a few of Dr. Agar's remarks with reference to differential aeration in terms of film stability. Had the research been continued—and it was to be hoped that it would be, because it was of very great interest—he would have suggested that Dr. Agar should carry out measurements, in the very skilled way described, in rather different conditions. When long-term corrosion experiments were carried out it would be found in many types of conditions that the protected areas which were well defined in an early stage of corrosion gradually contracted until eventually they disappeared altogether and the whole surface of the specimen was corroded; to a very large extent the areas which were originally uncorroded gradually caught up with the areas which were first corroded. It would be very interesting to follow up by Dr. Agar's method exactly what happened during those changes, but unfortunately it would probably be necessary to wait rather a long time before Dr. Agar could give that very interesting information.

The work on paints by Dr. Mayne and on corrosion-fatigue by Dr. Gould seemed to promise results which should have important industrial applications in the not-too-distant future, and it was a great pity that it had been necessary for Dr. Mayne's experiments to be slowed down and for Dr. Gould's research to be abandoned altogether for the time being. However, since Dr. Mayne's work was being continued to some extent, and Dr. Hoar's was also being continued, something had been saved out of the wreck.

Dr. W. H. HATFIELD, F.R.S. (Vice-President, Sheffield), said that the Corrosion Committee valued very much indeed the work of the school which Dr. Evans had created at Cambridge for dealing with corrosion, and only regretted that the exigencies of the moment had led to a curtailment of the collective effort. The sooner Dr. Evans could see his way to reinstate and pursue the work that had been in hand the more the Committee would be delighted. Personally, he felt that the work by Dr. Mayne promised very well

indeed, and the results which might arise from that particular research would more than justify the whole of the support that had been accorded to the work at Cambridge. It was a very good plan that Dr. Evans should put before the Institute a statement of the researches which had been in progress and the position at which they had arrived.

Dr. T. P. HOAR (Cambridge) remarked that he wished to say a few words about the very elegant experiments of Dr. Agar. The method used seemed to be capable of application to one or two other cases of both academic and practical importance to which Dr. Agar had not had time to apply it, and there was one such case of particular interest that would perhaps appeal to Dr. Bengough.

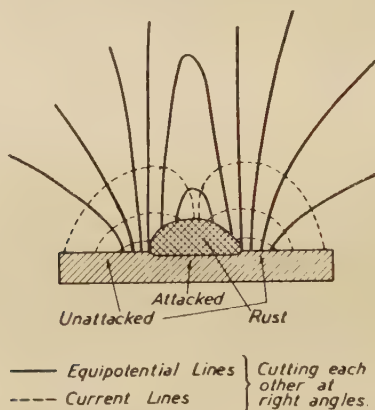


FIG. A.—Equipotential Lines during Flow of Current between Attacked and Unattacked Zones.

In the case of the totally immersed corrosion of steel in saline media, either under practical conditions or under the standardised conditions that Dr. Bengough and his collaborators had investigated, it was often found that corrosion took place over a certain area only, where there was a "mound" of rust, and that the rest of the specimen was free from attack. There had been controversy as to whether the cathodic process took place at the unattacked zone or underneath the mound of rust at points adjacent to the anodic points. Dr. Agar's method, which required neither a knowledge of where corrosion was going to occur nor any electrical connection to the corroding metal, could be readily applied to such conditions; and the equipotential lines would show immediately whether or not current was flowing between the attacked and unattacked zones. If it was, the equipotential lines would appear as shown in Fig. A. If, on the other hand, the equipotential lines

were not of that form, it would show that there were no effective cathodes outside the rust mound.

It was very satisfactory to find that this new and very much refined method gave results which were in complete agreement with the less accurate measurements made by Dr. Evans, Bannister and Britton,<sup>1</sup> and by the author and himself<sup>2</sup> nearly ten years ago in the author's laboratory. It was then found that there was a distinct potential difference between the corroding part of the metal and the unattacked part; the potential difference was of the same order of magnitude (for similar solutions) as that now found by Dr. Agar's very much more delicate method. Furthermore, it was also suggested then that the current lines went right up to the surface of the liquid, the cathode being situated within a millimetre or two of the liquid surface, as Dr. Agar had now quite conclusively proved.

Mr. A. W. HOTHERSALL (London) wished to ask Dr. Evans one or two questions about the method of testing the protective value of oxide films by copper nitrate spots. The method seemed to have possibilities and to be important, and it was therefore necessary to be quite certain that the mechanism of the reaction was understood. Was Dr. Evans quite sure that the oxide film acted as a cathode for the deposition of copper? He asked that question because his experience of the electro-deposition of copper had shown that the presence in local areas of a very slight amount of film (*e.g.*, oxide, colloid, etc.) was sufficient to inhibit the deposition of copper, presumably by exerting a very slight local resistance which was sufficient to stop the metal depositing on that spot and to concentrate it somewhere else. This principle had in fact been used to compare the tendency of various solutions to produce oxide films on nickel surfaces<sup>3</sup>; clean nickel specimens were half immersed in the solution under test and then totally immersed as the cathode in a copper-plating bath. When an oxide film had been formed on the nickel, the copper deposit was confined to the upper half of the specimen. For that reason he wondered whether, where the bare steel was exposed at the site of breaks in the oxide film, there was not a sufficient number of local anodes and cathodes to cause deposition of the copper there. In that connection also it would be very interesting to know whether Dr. Evans had done any experiments with this copper nitrate reagent on scratches made on thick invisible films, which Vernon had shown could be produced by heating at 200° C., for comparison with the behaviour on thinner but visible films.

In view of what he had said, he wondered whether Dr. Evans'

<sup>1</sup> Evans, Bannister and Britton, *Proceedings of the Royal Society*, 1931, A, vol. 131, p. 357.

<sup>2</sup> Evans and Hoar, *Proceedings of the Royal Society*, 1932, A, vol. 137, p. 343.

<sup>3</sup> A. W. Hotherhall, *Journal of the Electrodepositors' Technical Society*, 1937, vol. 13, No. 12.

results might possibly be explained, at least partially, by taking into account the properties of the oxide film itself, for example, the chemical properties and the electrical resistivity, and whether they might have a bearing on the way in which the copper deposited.

With regard to Dr. Evans' reference to the malleability of the film produced when iron was immersed in a chromate solution, he believed that there was good reason for thinking that in the case of zinc immersed in a chromic acid solution and given a protective film by a certain trade process, the film produced contained slightly soluble chromium compounds which very slowly leached out. That film was protective for a long time when zinc was fully immersed in water, and he had heard it suggested that the long period of protection was due to some extent to a slow leaching out of the chromate, which kept the protective film in repair. He believed that the film formed on iron by immersion in a chromate solution also contained chromium compounds, and he wondered whether the same explanation was possible in that case also, namely, that the slow leaching out of the chromium compounds adjacent to a scratch would stop corrosion at the scratch line.

Dr. T. SWINDEN (Member of Council, Stocksbridge, near Sheffield) said that he shared the regret of all those conversant with the work of Dr. Evans and his co-workers at Cambridge University that any of the programme upon which they had been engaged had been interrupted by the war, and he expressed the hope that resumption of this work would not be long delayed.

Two of the subjects mentioned were of obvious practical value. As stated by Dr. Evans, the work of the Corrosion Committee had indicated the ideal conditions necessary for the protection of steel by painting, but it was self-evident that in many cases these conditions would not be attained. Work on the development of a paint for application to steelwork under unfavourable service conditions was clearly of the greatest commercial importance, and a complete solution of this matter would be one of the greatest contributions to the problem which really had given birth to the Corrosion Committee, namely, the minimisation of the loss and inconvenience arising from corrosion.

The work on corrosion-fatigue was in a slightly different category, but similarly had immense practical importance. The members of the Corrosion Committee would remember the enthusiasm with which Dr. Evans' proposal to examine this subject from a new angle had been accepted. Hitherto most of the work on corrosion-fatigue had consisted in showing how the resistance to fatigue was minimised by this or that corrosive influence. Dr. Evans had suggested work in the direction of determining the "inhibition factor" of various corrosive conditions, namely, the amount of a given type of inhibitor which would counteract the effect of the corrosive conditions in reducing the resistance to fatigue. The



work evolved along the lines outlined in this paper, which had a more practical bearing than the initial programme of work indicated. Here, again, it was impossible to forecast the extent of the practical importance which would attach to an establishment of principles that applied so as to counteract corrosion-fatigue where material had to operate under corrosive conditions.

Mr. T. HENRY TURNER (Doncaster) said that the scientific part of the paper had already been dealt with very well by other speakers, but there was one comment which had not yet been made and which might be of use to Members of the Institute. The author spoke of endeavours to find a means of painting, first, wet steel, and then steel that had scale on it, and he seemed to have arrived at fair prospects of success with regard to wet steel. That in itself would be a great achievement, even if success with regard to painting steel with some scale on it was not yet achieved. In that connection a new process was being spoken of at present, namely, "flame-descaling," *i.e.*, treating steelwork with a flame and wire-brushing it before painting it while still warm.

The author referred both to the work done by his team at Cambridge and to that carried out by Dr. Hudson and said it had "indicated that admirable protection can be obtained over long periods even in severely polluted atmospheres, provided that inhibitive paint"—which in practice generally meant red lead—"followed by two suitable coats chosen for their mechanical properties, has been applied to a surface free from moisture, scale, rust and salt." Of course, the first difficulty in commercial practice was to obtain a surface free from moisture and dirt. He (Mr. Turner) had painted panels, 18 in. by 9 in., treated either by wire-brushing or by sand-blasting, painting them in a laboratory, leaving 48 hr. between the coats and keeping the panels for seven days indoors before exposing them, and under perfectly uniform conditions he had found over a period of ten years that there was a very important difference in the life of the coats on the top of the red lead. He would therefore be glad if the author would amplify what he meant by "two suitable coats." He himself had tried half a dozen paint treatments of three coats, starting with one, or sometimes two, coats of red lead, and with red oxide on the top, which would give him six years' or more good life in industrial atmospheres, but he could put on two coats of red lead and two coats of other paints and they would fail in one year, or at least not last two and a half years. Even four-coat treatments starting with red lead were not always satisfactory. He did not wish to suggest that red oxide was the only paint to follow red lead in painting, because Dr. Hudson and he had inspected one of his Company's bridges just about this time last year, on which 95% of the surface was in fine condition, although it had been painted in 1920 with red lead followed by a green paint consisting of barytes, lead chromate and prussian blue.



Therefore paint could do amazingly well and have a very long life if the choice of material and the preparation were right, and care in such matters would enable industry to save thousands of pounds in maintenance costs every month, if the right advice could be given.

He could not enumerate all the paints which were unsatisfactory on the top of the inhibitive red lead, but they seemed chiefly to be such as gave hard glossy surfaces. If one put a glossy hard finish on to red lead the result was usually a very short life, and the coats which gave exceptionally long lives were generally the iron oxides on red lead.

Red lead was a very soft paint, vulnerable by abrasion and weathering in a short time if unprotected, but the paint used to protect the red lead must be chosen so that the successive coats were compatible one with another, and it would seem that whatever pigments were used, the vehicles which produced glossy paints were not compatible with red lead as a priming coat. In many of his tests the dissimilarity in hardness, shrinkage or elasticity appeared to have resulted in the surface coats actually decreasing the life of the red lead.

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#### AUTHOR'S REPLY.

Dr. U. R. EVANS, in replying to the discussion, said he would like to thank those who had taken part. He particularly appreciated the kind words of Dr. Bengough and the encouraging remarks of Dr. Hatfield, to whom the Cambridge Corrosion School owed so much.

He agreed with Dr. Bengough that it would be interesting to apply Agar's electrical method to specimens corroding under different conditions, but there might be a difficulty in applying it in long-term experiments, since an accumulation of corrosion product might interfere with the electrical measurements. Thornhill's qualitative work on half-immersed zinc,<sup>1</sup> designed to study the distribution of corrosion, was carried out for fairly long periods, and it was found that, under the conditions adopted (*N*/1000 sodium chloride and half-immersed specimens, with care to avoid any alteration of level through evaporation), there still remained protected areas in the meniscus zone after 82 days, with intense corrosion just below it, although in some cases the corroded area extended up to the head of the meniscus at some points.

In papers published about 1925-26,<sup>2</sup> he had described experiments in which specimens, both of zinc and of steel, were partially immersed in chloride solutions for relatively long periods. It was found that the corrosion started low down and tended to move up, as Dr. Bengough had described, towards the water line. In the case

<sup>1</sup> R. S. Thornhill and U. R. Evans, *Journal of the Chemical Society*, 1938, p. 2109.

<sup>2</sup> U. R. Evans, *Industrial and Engineering Chemistry*, 1925, vol. 17, p. 363; *Journal of the Society of Chemical Industry*, 1926, vol. 45, p. 37T.

of commercial rolled zinc (tested with an as-rolled surface) he had often obtained a perfectly horizontal line of demarcation between the corroded area and the non-corroded area; this line moved up *continuously*. In the case of abraded steel, the boundary was irregular and moved up *discontinuously*. It was very possible that, had the experiments continued still longer, the corrosion would have reached the water-line itself. Even at such a stage, the electrochemical mechanism might still have been the same; in the early stages of the experiment a damp zone due to the creepage of alkali appeared above the water-line, and it was quite possible that this "creep zone" might ultimately come to act as the cathodic area, when the anodic area lay along the water-line. In discussing water-line corrosion, it was necessary to distinguish between corrosion at the meniscus head and corrosion at the meniscus foot. Until Thornhill's work, the important distinction between these two things was not recognized, at Cambridge or elsewhere. In any experiments designed to distinguish between meniscus-head and meniscus-foot attack, it was necessary entirely to avoid evaporation.

In regard to Dr. Hoar's suggestion that the electrical method should be used to study the corrosion of horizontal surfaces, Dr. Evans thought that it should be capable of distinguishing between two possibilities, (1) a number of small anodes and cathodes very close together, and (2) relatively large anodes and cathodes occupying different parts of the specimen. If it so happened that large anodic and cathodic areas were found, then it should be possible to measure the electric currents and to ascertain whether they accounted for the whole of the corrosion or only a part. If, on the other hand, small anodes and cathodes were found intermixed, it would be difficult, certainly with the present form of apparatus, to measure the currents. Of course, it might be possible to refine the apparatus to deal even with that case, but it would not be very easy.

He wished to thank Dr. Hatfield very much indeed for his words and for all the interest and kindness he had shown throughout a long period. As soon as those aspects of the research which had been abandoned could be resumed, that would be done.

With regard to Mr. Hothersall's interesting and useful remarks, he thought there was evidence that the outside of the oxide film behaved as a cathode, at any rate in some cases. He remembered many years ago making some experiments on heat-tinted iron, placed in a copper salt solution; a layer of metallic copper appeared on the surface, and the interference colours disappeared. He then placed the specimen in ammonia, which, in the presence of oxygen, dissolved off the metallic copper, and the interference colours reappeared unchanged, indicating that the copper had been deposited upon the oxide film.

He agreed that one beneficial effect of chromate treatments was to leave a certain amount of soluble chromate in the pores or clinging to the film, so the film did constitute a reservoir of chromate in-

hibitor. He had noticed that in his own work. After treatment in chromate, an iron specimen was put in a vessel containing tap-water, and in cases where the water was not periodically renewed it slowly became yellow, showing that chromate was being leached out, notwithstanding the fact that the specimen had been washed after the chromate treatment.

He wished to thank Dr. Swinden for his very kind remarks about corrosion-fatigue. If it was possible to restart experiments on that subject, he would certainly do so.

He had been very much interested in Mr. Turner's remarks. He was glad that Mr. Turner had brought forward the question of the flame descaling of steel, since that process might prove very useful.

The meaning of the expression "mechanically suitable coats of paint" depended somewhat upon the conditions to which the metal had to be exposed. If Mr. Turner would refer to the report on the seven-year paint tests carried out by Mr. Britton and himself<sup>1</sup> which included specimens exposed in London, Cambridge and elsewhere, he would find a number of three-coat combinations which had given good service. On the whole, these seemed to be much the same combinations as those which had given good service in Mr. Turner's tests.

He would not care to say why some of Mr. Turner's four-coat specimens had been unsatisfactory, but he was interested in the statement that those which had gloss coats outside behaved badly. In some early work which Mr. Haines and he had carried out,<sup>2</sup> they had found that under some conditions hard elastic coats behaved very much worse than relatively soft coats; if rusting started at a weak place in a coat, stresses were set up and, if the coat was very elastic, the stresses might be transferred from that place to others and the whole coat might peel off unchanged, whereas a soft coat would often yield to plastic flow until the danger was past, and then perhaps rust would fill up the gap, and to some extent stifle further attack. There was, however, another factor which he had recently heard mentioned by more than one authority. Normally inhibitive pigments embedded in a very waterproof vehicle failed to act as inhibitors; in order that red lead (for instance) should act as an inhibitor, a solution of red lead or of litharge was required, and if the red lead was embedded in (say) a synthetic-resin film which was itself entirely waterproof, the inhibitive properties of the red lead could not be exerted.

<sup>1</sup> S. C. Britton and U. R. Evans, *Journal of the Society of Chemical Industry*, 1939, vol. 58, p. 90.

<sup>2</sup> U. R. Evans and R. T. M. Haines, *Journal of the Society of Chemical Industry*, 1927, vol. 46, p. 363r.

# THE ESTIMATION OF HYDROGEN IN STEEL AND OTHER METALS.\*

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(Fig. 1 = Plate VII.)

*Paper No. 2/1940 of the Heterogeneity of Steel Ingots Committee  
(submitted by the Oxygen Sub-Committee).*

## SUMMARY.

An account is given of the development of the vacuum-heating method of estimating hydrogen in metals (especially steel). The theoretical basis of the method is discussed, and a description of an apparatus designed for the study of the hydrogen content of metals is given together with results of tests upon the method itself and upon metal samples. The rate of evolution of hydrogen from steel at various temperatures has been studied, and it is confirmed that the amount of hydrogen given off by this method is the same as that by the vacuum-fusion method.

## INTRODUCTION.

SINCE about the beginning of the present century, the ever-growing and more exacting requirements of the engineer have caused the metallurgist to devote more and more of his energy to improving the quality of his product. An enormous amount of fundamental research has been conducted into the correlation of the physical properties of metals (especially steel) with their precise mode of production, their chemical composition and their constitution. The discovery that very small additions of other elements can radically affect the properties of metals has added impetus to the development of micro-chemistry, but there are certain non-metallic elements which, whilst influencing the properties of metals, even when present in minute amounts, call for a specialised technique, more physical than chemical, since they enter or leave the metal in the form of gas.

Foremost among the gases which influence the properties of metals is hydrogen, and the object of this paper is to describe an apparatus which has been developed at the Brown-Firth Research Laboratories, Sheffield, for the accurate estimation of hydrogen in metals. The author is indebted to the director of these Laboratories, Dr. W. H. Hatfield, F.R.S., as well as to the other directors of the associated companies, for permission to publish the information herein given, and it is the author's earnest desire that the details

\* Received February 14, 1940.



to be found in this paper will be of assistance to others seeking to apply the fruits of science to constructive purposes.

Much of the earlier work upon the gases present in metals was hampered by the fact that the necessary vacuum equipment was not then available, and whilst it is interesting and instructive to examine the writings of the earlier workers in this field, their analytical results and their consequent conclusions must be viewed in relation to the times in which the experiments were made. Graham analysed the gas given off from various specimens of iron and found carbon monoxide, carbon dioxide and nitrogen in addition to hydrogen. Parry <sup>(1)</sup> in 1872 obtained large volumes of gas, over 80% of which was hydrogen, by heating iron in a vacuum produced by the then newly-devised instrument, the Sprengel pump. Likewise about the same time (1880), Dumas, heating 200 g. of aluminium well above its melting point, extracted gas, 98% of which was hydrogen. Somewhat later Belloc <sup>(2)</sup> studied the effect of temperature upon the rate of evolution of gas from very mild steel, and found that the composition of the gas depended upon the proximity of the temperature of heating to the critical points of the steel. Baker <sup>(3)</sup> in 1909 made a careful examination of the gas given off from steel, using a method of steadily heating and cooling a steel sample and measuring the quantity and composition of the gas in relation to the temperature. He observed that at 690° C. an arrest ( $\text{Ar}_{123}$ ) in the temperature was accompanied by a big evolution of carbon monoxide, whilst hydrogen reached its maximum rate of evolution at a somewhat lower temperature.

In 1918 the Faraday Society held a general discussion upon the "Occlusion of Gases by Metals," which has since been published,<sup>(4)</sup> and to which reference should be made for a summary of the various views held at that time.

The more recent work which has been done upon the hydrogen content of metals has, for the most part, utilised modern high-vacuum technique in the light of the theoretical advances which have been made. The consequence is that, as usual, our knowledge is both more complete and more complex. The mechanism whereby hydrogen is taken up by, or liberated from, a metal involves the processes of adsorption, solution and diffusion. It is to Langmuir <sup>(5)</sup> that we owe the concept of a mono-molecular layer of physically adsorbed gas. More recently the work of Roberts <sup>(6)</sup> on the hydrogen-tungsten system and the work of Mann and the present author <sup>(7)</sup> on the hydrogen-platinum and deuterium-platinum systems indicate that where some chemical affinity exists between the gas and the metal, then at normal temperatures a layer of gas is chemisorbed even at very low gas pressures. The method of examining the metal surface in these experiments consisted of a measurement of the accommodation coefficient of neon or helium upon the surface. The importance of this to our considerations here is that since adsorption is a necessary preliminary to the diffusion and solution of



the gas in the metal, the rate of removal of the gas from the metal will be influenced by (if not primarily dependent upon) the rate of the desorption processes. Since an adsorbed layer of gas can be quite stable upon a metal surface even in quite low gas pressures, it seems likely that in much of the work which has been done upon the removal of gas from metal, the long period of time found necessary for complete removal is due to the fact that the extraction pressure has not been low enough, so that the diffusion process has been hindered by the adsorbed layer. In the apparatus to be described a high vacuum is maintained by a mercury-vapour pump in continuous operation, and it is suggested that this may account for the relatively short period of time found necessary for complete extraction of the hydrogen.

At temperatures at which the diffusion of hydrogen through metals can be measured, adsorption is of the activated type, and since thermo-chemical data for activated adsorption indicate dissociation of the diatomic hydrogen molecules, it is not surprising that the rate of diffusion is proportional to the square root of the gas pressure. However, at low gas pressures the rate of diffusion of hydrogen deviates from the square-root relationship and approximates more to a proportionality to the pressure.<sup>(8)</sup> Since these measurements of diffusion involve the gas pressure external to the metal surface, the process of adsorption may influence them, so that it is quite possible that at low gas pressures the condition of the adsorbed gas may control the passage of gas through the metal.

As regards the effect of temperature upon the rate of diffusion of hydrogen through metals, both experiment and theory give an exponential relationship, so that for the elimination of the gas from the metal it should only be necessary to exceed a certain temperature, and then the rate of elimination should increase rapidly with rise in temperature. This was found to be so for steel, as will be seen from the family of graphs shown in Fig. 3.

The solubilities of hydrogen in metals, examined so carefully by such workers as Sieverts<sup>(9)</sup> and Iwasé and Fukushima,<sup>(10)</sup> are of interest to the present work as showing the likely quantities of gas which one would expect to find in the metals examined. It is of particular interest to note that the quantities of hydrogen found in steel are of the order of the solubility in iron up to temperatures approaching the melting point, and that the usual amount observed present corresponds to saturation at about 600° C., i.e., to the temperature at which diffusion is beginning to slow up.

The present-day method of estimating the hydrogen content of metals is by melting *in vacuo*, and the author has already described<sup>(11)</sup> the apparatus in use in these laboratories for this purpose. The work of the Oxygen Sub-Committee of the Iron and Steel Institute having shown decisively that the effect of hot-working upon steel was to reduce the hydrogen content, Sloman<sup>(12)</sup> determined the gas given off from several steel samples when heated *in vacuo* to a

temperature of 650–700° C. His results show that after a period of heating of up to 2 hr. gas ceased to be evolved, and that the gas was hydrogen corresponding in amount to that obtained by vacuum fusion. These conclusions have been substantially confirmed and amplified by the present author, and the apparatus described has been designed and constructed to determine the hydrogen content of a dozen or more metal samples consecutively with a minimum of elaborate apparatus, and using this vacuum-heating method.

### RESULTS AND APPLICATIONS.

Since vacuum-fusion is the method generally accepted as reliable, and has for a long while been employed in these laboratories with great confidence, a careful comparison with results obtained by this method has been kept throughout the investigation; the same-sized samples were used throughout ( $\frac{1}{2}$ -in. cylinders,  $\frac{1}{2}$ -in. long). The possible error due to the "blank" in the vacuum-fusion apparatus was higher than was desired (sometimes amounting to 0.00005% of hydrogen on the metal sample). However, differences between the results by the two methods were for a while greater than this, even when the vacuum-heating method was operating under what were found to be the optimum conditions. The reason for this, we are sure, was not due to error in either method, but rather to segregation of the hydrogen in different parts of the metal, or else to the loss of hydrogen resulting from the sample getting too hot during machining. Samples which had a normal hydrogen content were found to give a somewhat lower value if during machining the piece became too hot to handle, or still more so if there was any temper-colouring produced upon the surface. Small steel castings were found to vary considerably in their hydrogen content at different parts, and much of our earlier perplexities were connected with this fact.

Table I. shows a comparison of the results by the two methods for a number of metal samples. There appears to be a tendency for the vacuum-fusion method to give slightly higher results than the vacuum-heating method. The reason for this appeared to be that the heating treatment had not extracted all the hydrogen, but the fact that several samples on vacuum-fusion subsequent to vacuum heating gave no further evolution of hydrogen discredits this view. The number of significant figures given has been reduced so as to make full allowance for the experimental error of each method, and it will be seen that the accuracy of the heating method is ten times that of the fusion method. The temperature of operation for the heating method was 600° C., excepting for the aluminium alloy samples, which were found not to give off their hydrogen until they were actually molten. These aluminium alloy samples were therefore inserted in small slip-cast alundum thimbles, in which they were melted in the furnace at about 700° C., cooled out of the furnace and

when solid again manipulated in their thimbles as solid metal samples. The results for these aluminium alloys have not been stated as accurately as for the iron and steel samples, since there

TABLE I.—*Comparison of the Results Obtained by the Vacuum-Fusion and by the Vacuum-Heating Methods.*

Sample.	Hydrogen, %, by—	
	Vacuum-Fusion Method.	Vacuum-Heating Method.
0.08% carbon steel (cast 52703)—		
ingot . . . . .	0.00035	0.000340
2-in. rolled slab . . . . .	0.00015	0.000130
$\frac{3}{4}$ -in. rolled bar . . . . .	0.00015	0.000110
box test . . . . .	0.00015	0.000125
0.20% carbon steel, forged bar . . . . .	0.00010	0.000100
3% nickel steel—		
ingot top . . . . .	0.00065	0.000620
ingot bottom . . . . .	0.00095	0.000920
4.5% nickel steel—		
forged . . . . .	<0.00005	0.000015
box test, unkilld . . . . .	0.00005	0.000067
same cast, box test, aluminium-killed . . . . .	0.00020	0.000175
4.5% nickel steel—		
ingot bottom . . . . .	0.00005	0.000040
bath sample . . . . .	0.00010	0.000060
another bath sample . . . . .	0.00025	0.000230
5% nickel steel, ingot bottom, outside . . . . .	0.00020	0.000170
18% chromium, 8% nickel steel—		
bath sample . . . . .	0.00060	0.000675
another bath sample . . . . .	0.00090	0.000870
ingot top . . . . .	0.00095	0.00109
same cast, ingot bottom . . . . .	0.00100	0.000995
box test, unkilld . . . . .	0.00085	0.000840
Swedish iron, 0.04% carbon . . . . .	0.00020	0.000200
Aluminium alloy, 4% copper . . . . .	Operating temperature too high.	0.00021
" " " " . . . . .		0.00017
" " 12% silicon . . . . .		0.00015
" " " " . . . . .		0.00018

have not been any independent checks and the conditions under which the gas is evolved have not been so closely studied.

The rôle of hydrogen as a possibly deleterious constituent of metals is well recognised, and this apparatus not only has its applications in this direction, but also for the fundamental study of gas-metal equilibria, and the solution and diffusion of hydrogen in alloys.

## DESCRIPTION OF THE APPARATUS.

Fig. 1 is taken from a photograph of the apparatus, whilst Fig. 2 is a diagrammatic sketch showing its working principles. The

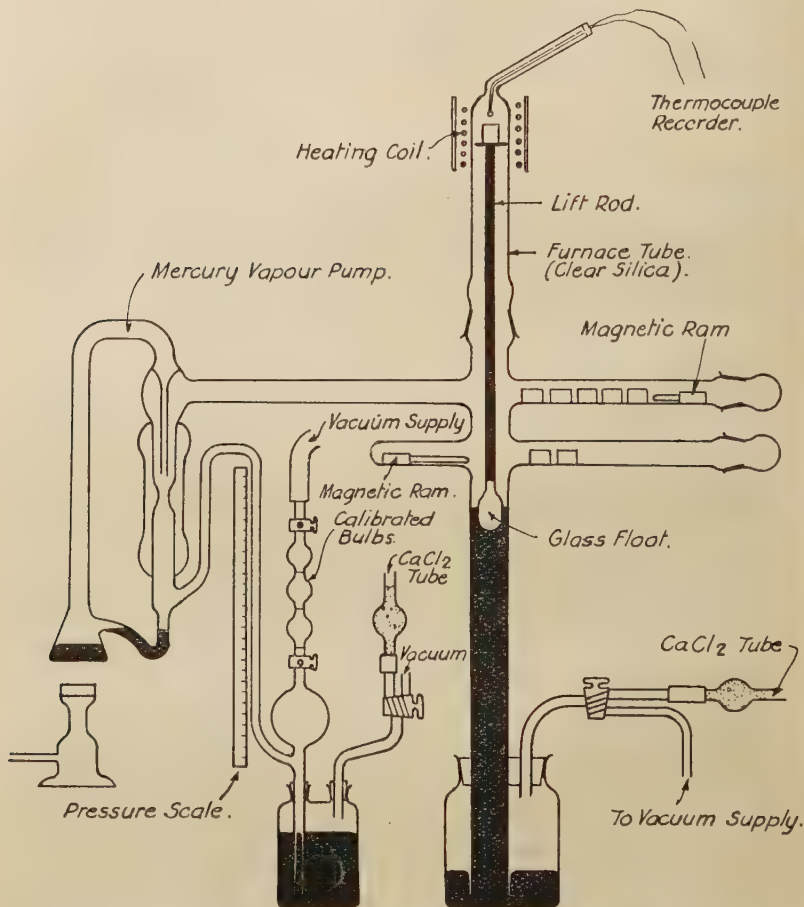


FIG. 2.—Diagrammatic Sketch of the Apparatus Used for the Vacuum-Heating Method of Estimating Hydrogen.

heating furnace is a fused-silica tube round the upper end of which a well-lagged nickel-chromium resistance coil is wound. This silica tube has a ground joint at its lower end, which fits a corresponding pyrex-glass tube leading to a glass mercury-vapour pump. For convenience this mercury-vapour pump is also in pyrex glass,



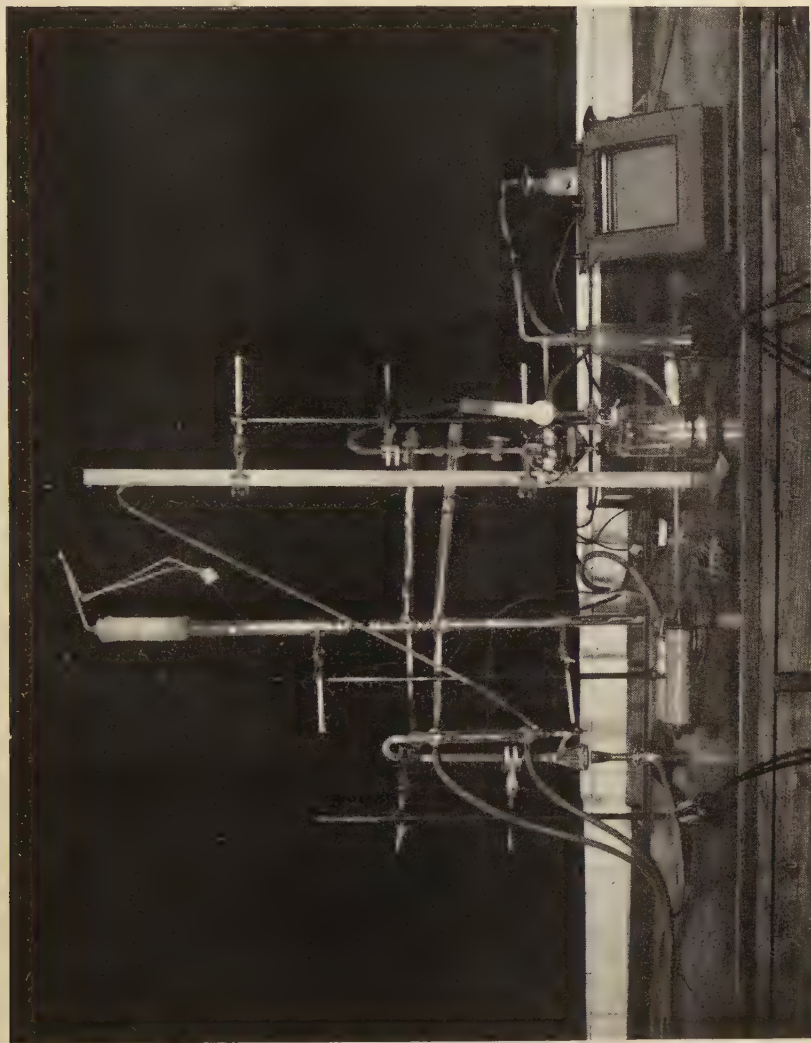


FIG. 1.—Apparatus Used for the Vacuum-Heating Method of Estimating Hydrogen.





so that from the silica-joint onwards the apparatus, through which the gas has to pass, is in one piece, the mercury-vapour and the Töpler pumps having been sealed-on in position. The mercury-vapour pump is connected, *via* quill glass tubing, to a combined Töpler pump and McLeod gauge, the function of which is both to collect the gas and measure its quantity. The upper portion of this pump (which is called a Töpler pump for convenience) is joined to three small calibrated bulbs, isolated by taps, into which the gas collected can be compressed and its volume and pressure recorded, by taking the height of the mercury in the adjacent vertical tubing. These bulbs are graduated, the upper one being smaller than the middle one, which is itself smaller than the lower one, so that considerable variations in volume of gas can be dealt with. About seven-eighths of the gas collected is swept up and compressed by one operation of the Töpler pump, so that in order to save time in taking readings of gas quantity, only one sweep of the pump was normally taken, and the precise factor, to convert this quantity measured to the total quantity of gas given off from the specimen, was experimentally determined.

A striking feature of the apparatus is the mercury lift used to move the samples vertically in and out of the furnace. A sealed glass bulb floats upon the mercury surface in the central glass tube, and supports a long steel rod on the top of which a steel platform is attached to support the metal samples. The position of this platform together with its sample is determined by the pressure in the bottle on the right-hand side of the sketch, and out of view in the photograph, since it is below the bench level. Thus by a turn of the three-way tap either to the atmosphere or else to the vacuum supply, the platform can be brought to :

(1) The level of the upper horizontal tube containing unexamined metal samples, for the purpose of a sample being magnetically pushed on the platform ;

(2) the level of the centre of the furnace, near which is a thermocouple for the purpose of recording the temperature ;

(3) the level of the lower horizontal tube, into which the metal sample is magnetically pushed after its heat treatment.

This mode of performing mechanical operations *in vacuo* with the aid of mercury surfaces, controlled externally, has proved itself very valuable, and superior for the present purpose to the purely magnetic control at first employed.

#### THE PRELIMINARY EXPERIMENTAL WORK.

##### *The Composition of the Gas Evolved.*

The experiments of others, to which reference has already been made, indicated that under certain conditions gas other than hydrogen could be given off from metals on heating, so that in the

original form of this apparatus an activated-charcoal pocket was sealed in between the furnace and the mercury-vapour pump. This was employed as a quick means of determining the actual amount of hydrogen as well as the amount of other gas, since in a high vacuum charcoal does not absorb any permanent gas unless the temperature is artificially lowered, when, at the temperature of liquid air, all gases except hydrogen are absorbed. The method of examining the gas was, therefore, to measure the quantity which passed through the charcoal pocket when surrounded by liquid air; this gave the hydrogen value. Then by removing the liquid air and allowing the charcoal to warm up to room temperature, any increase in the reading corresponded to gas other than hydrogen. On several occasions the total gas collected was removed to a gas-analysis apparatus and analysed, but this was not considered a necessary part of the research, since it was hydrogen with which we were primarily concerned. Water vapour was invariably a constituent of the gas collected, unless the metal samples used were very bright and clean—and even then they came out of the apparatus brighter than when they went in. Where the quantity of water vapour was considerable, small droplets of water were visible in the Töpler pump during the compression of the gas. The simplest method used for detecting water vapour, when the quantity of it present was small, was to observe the pressure of the gas when it was compressed to different stages. Any departure of the product of the pressure and the volume from being a constant indicated water vapour. Since the presence of water vapour was invariably associated with a brightening-up of the surface of the metal, it is reasonable to assume that the water vapour was produced by a reduction of an oxide film by the hydrogen being evolved from the surface. However, in such a reaction :



the volume of the water vapour formed is equal to the volume of hydrogen oxidised, so that, provided that no water is actually condensed out in the form of liquid, the volume of the system remains unaltered by the reaction. Hence all the metal samples were very carefully cleaned before examination, and the gas evolved was not unduly compressed.

Under all the conditions of study the gas given off from steel was substantially hydrogen, but at temperatures above 700° C. small amounts of carbon monoxide and nitrogen made their appearance, particularly the latter. As the temperature was raised the quantities of these gases evolved increased, and at a temperature of 1000° C. nearly 10% of the total gas was accounted for in this way. It will be noted that the apparatus was designed so as to avoid contact between the metal samples and the heated silica furnace tube, since it has been suggested that oxidation of carbon from steel can take place in this way. Certainly the quantity of carbon monoxide

found was small, and the most which was collected at a temperature of  $1000^{\circ}\text{C}$ . only corresponded to 0.0008% of oxygen in the steel so treated. Nitrogen was given off in somewhat larger quantities at these higher temperatures, and for the sample just referred to the nitrogen corresponded to 0.003% of nitrogen in the steel. The total nitrogen content of this steel, as shown by vacuum-fusion, was only 0.008%, so that a substantial proportion had been driven off from the solid.

### *The Blank.*

In an apparatus of this kind, constructed in glass and silica and having no graphite parts, the question of the "blank" really does not arise. The normal high-vacuum technique is applied in its construction, and the whole is thoroughly out-gassed before use. The furnace itself never caused any permanent evolution of gas, and that which was given off during the out-gassing period was mainly water vapour. For the sake of interest the "blank" was determined over a period of a month when the apparatus was not being otherwise used. The figure obtained came out at 0.00001 ml. per hr., and this is probably due to incomplete out-gassing rather than a leak. Hence no regard has to be taken at all for any "blank" correction.

### *The Effect of Temperature.*

Temperature readings were obtained by a thermocouple and recorder, the thermocouple being inserted in a narrow tube at the top of the furnace and projecting down towards the centre of the furnace. The metal sample and platform were brought up close to the thermocouple, and the uniformity of the temperature was checked by bringing the metal sample into contact with the thermocouple, when no change in the reading was observed. At the higher end of the temperature range the temperature of the thermocouple and the sample were found to be closely the same when using a disappearing-filament pyrometer.

The effect of temperature upon the rate of evolution of hydrogen was studied using a steel sample somewhat high in the gas, since it was thought that if the gas was present in the steel in different forms, then such a study ought to give evidence of the fact. Actually no such evidence was obtained. A number of samples were cut from closely adjacent positions in an ingot, and were raised into the furnace at different temperatures, the hydrogen given off being measured at frequent intervals of time. It was found that gas was rapidly given off at temperatures above  $500^{\circ}\text{C}$ ., the initial lag being reasonably accounted for as the time required for the sample to be heated. Above  $900^{\circ}\text{C}$ . the rate of evolution of hydrogen was so rapid that accurate readings could not be obtained quickly enough, whilst below  $400^{\circ}\text{C}$ . the rate became distinctly slow.

The conclusion of importance which was reached was that the total amount of hydrogen given off from the steel was independent of the temperature to which the steel was heated—this will be seen from the graphs reproduced in Fig. 3—and that this amount was

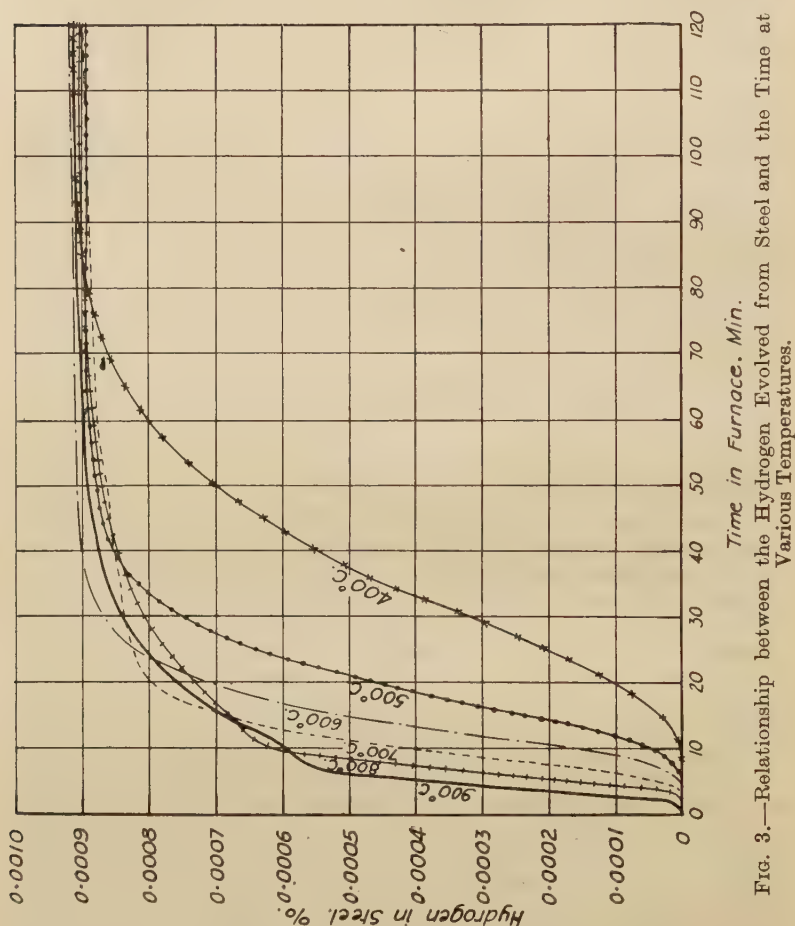


Fig. 3.—Relationship between the Hydrogen Evolved from Steel and the Time at Various Temperatures.

equal to the amount given off by vacuum-fusion. It will be observed from these graphs that at temperatures above 700° C. the curves show an irregularity which causes them to cross. The most likely explanation of this phenomenon is that on passing through the  $Ac_1$  point the liberation of the hydrogen is in some way hindered.

After it had been shown that no further evolution of hydrogen



occurred when steel samples, which had already been vacuum-heated, were melted *in vacuo*, the conditions of extraction were standardised at 600° C. for 1 hr. These conditions have been proved satisfactory for many different types of steel, but occasionally it is found that hydrogen is still being very slowly evolved after the period of 1 hr. If this occurs, then the period of heating is extended, maybe to 2 hr. or more, until a constant value is obtained. No explanation of this effect can as yet be given, though it is thought to be possibly related to the influence of the structure of the steel upon the diffusion of hydrogen.

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## DISCUSSION.

Dr. T. SWINDEN (Member of Council, Stocksbridge, near Sheffield) said that the essential feature of this paper was to show agreement between the hydrogen content as determined by vacuum fusion at, say, 1700° C. and vacuum heating at 600° C. Table I. revealed close agreement between the two sets of figures for a considerable variety of plain and alloyed steels, and it indicated the usefulness of the vacuum heating method in the case of alloys of comparatively low melting point. The simplified equipment used by Dr. Newell rendered the determination of hydrogen a much easier proposition and obviated the necessity for the comparatively expensive equipment required for vacuum fusion.

In welcoming these new data, one was bound to point out that the major facts were not new, although previously published literature had not embraced such a wide variety of steels. Thus, Mr. Sloman, in the Eighth Ingot Report,<sup>1</sup> showed complete agreement between vacuum fusion and low-temperature (650–700° C.) vacuum extraction for a series of seven steels, and the work which Mr. Stevenson and he (Dr. Swinden) had done on fractional extraction indicated very definitely that hydrogen was evolved in the lower fraction. This did not in any way detract from the value of Dr. Newell's paper, particularly the work on the effect of temperature and time on the rate of hydrogen evolution.

Attention might be drawn to what appeared to be a comparatively minor matter, namely, that Dr. Newell had reported his results as a percentage of hydrogen by weight, whereas it had generally been found convenient hitherto to report them in the form of millilitres per 100 g. of steel. The latter had the advantage of occupying less space and being easier to remember, but, in so far as this might convey to the reader the idea of proof that hydrogen, as distinct from oxygen and nitrogen, existed in steel in gaseous form, it was somewhat in anticipation of proven fact. An additive note on this subject would be welcomed, together with a statement of the conversion factor.

The author had confined himself, wisely, to the estimation of hydrogen in this paper, and the only additional factor which would bear repetition and emphasis was the well-known fact that the hydrogen content obtained depended on the time elapsing between casting the steel and testing, and on subsequent manipulative processes.

The paper was opportune, because of the greatly increased interest now being exhibited in the hydrogen content of steel. Many workers anticipated that it was in this direction that an explanation for certain characteristics which had puzzled metallurgists for a considerable time was to be sought.

<sup>1</sup> Eighth Report on the Heterogeneity of Steel Ingots, *Iron and Steel Institute*, 1939, *Special Report No. 25*, pp. 52–53.

Dr. D. BINNIE (Irlam, near Manchester) said there was no need for him to emphasise the fact that the paper was a very good one and full of valuable suggestions for future workers.

He noticed in Table I. that the 3% nickel steel contained 19 times as much hydrogen as the 4.5% nickel steel; he was referring to the figures for the ingot bottom, 0.00095% and 0.00005%. He would like to know the reason for that, as it would give a great deal of information on how hydrogen got into steel and how it stayed there.

Referring to Fig. 3, the author said "It will be observed from these graphs that at temperatures above 700° C. the curves show an irregularity which causes them to cross. The most likely explanation of this phenomenon is that on passing through the  $A_{c1}$  point the liberation of hydrogen is in some way hindered." He thought that that possibly bore directly on the cause of flakes in steel. Flakes seemed to be promoted by the depression of the  $A_1$  point in steel. In fact, one could almost tell beforehand what the tendency of a steel to flake would be from the depression of the  $A_1$  point, especially when that point was split into  $A_1'$  and  $A_1''$ .

Mr. J. H. WHITELEY (Consett, Co. Durham) said that there was one point in particular which he would like to bring forward in connection with this paper, and that was the possibility of non-metallic inclusions in the sample affecting the accuracy of the hydrogen estimation. Years ago Principal Edwards explained blistering in tin sheet as being primarily due to the presence of these inclusions. In the pickling process atomic hydrogen was absorbed, and diffused inwards until an inclusion was encountered, when its course was checked at the interface. The opportunity then occurred for the separated atoms to meet and combine into molecules. Since molecular hydrogen did not diffuse in steel, a quantity thus gradually collected, and eventually, when the sheet passed through the hot bath of tin, the pressure became sufficiently high to raise a blister. Now, he (Mr. Whiteley) noticed that, even at 400° C., which was about the tinning temperature, the whole of the hydrogen was stated by Dr. Newell to be evolved, and the question was, therefore, whether he had made sure that the presence of numerous heavy inclusions in the sample did not affect the result.

Mr. H. A. SLOMAN (Teddington, Middlesex) said he was very gratified indeed that the results obtained by the author confirmed those which he himself had published in the Eighth Report on the Heterogeneity of Steel Ingots.<sup>1</sup>

He was not quite sure that he agreed as to the respective accuracies which the author claimed for the vacuum fusion and the vacuum heating method, but that was a matter which they could go into at some future time.

He wished to raise a point in connection with the gases from

<sup>1</sup> *Iron and Steel Institute*, 1939, *Special Report No. 25*, Section VI., Part 2A.

aluminium alloys. In the case of steels it was known that the gas consisted practically entirely of hydrogen and therefore it required no analysis, but for aluminium alloys he had evidence that the gas was not by any means 100% hydrogen. He asked whether the author had found that and whether he had any figures for the other gases.

Another point related to the figures for the 0.08% carbon steel (cast 52703) in Table I. He himself had first made vacuum fusion determinations on that steel in 1937, and he had repeated them in 1938, obtaining exactly the same results. A little later, when he was developing the vacuum heating method, he had again determined the hydrogen in this particular steel by this new method. The results were in entire agreement with those obtained on the two previous occasions by the vacuum fusion method (*loc. cit.*). During that time the author had carried out similar tests by the vacuum fusion method, and he (Mr. Sloman) enquired whether the figures given in the Table were those which the author had obtained then. He had calculated them out roughly, and they seemed to him very similar. If that was the case, it meant that the figures in the left-hand column of the Table, yielded by the vacuum fusion method in the beginning of 1938, were confirmed by the figures which he presumed the author had obtained quite recently by the vacuum heating method. That was a very interesting further confirmation of the fact that hydrogen was not lost from steel in the cold, at any rate after the first few weeks after manufacture, and was important in the present connection for the following reason. The basis on which the author was using the vacuum heating method, *viz.*, testing several specimens one after the other, meant that the twelfth specimen, say, was subjected to the high vacuum for a considerable time before it actually got into the furnace. He personally did not believe that that made the slightest difference, because, although he had never done twelve samples straight off, he had done four or five, and he could not find any difference. He hoped the author would confirm that, because it was a very good point in the application of the paper. The more samples that one could do with one erection of the apparatus, obviously the better such apparatus was capable of works application.

He congratulated the author on the work that he had carried out, on producing such a simple and practical apparatus for the determination of hydrogen and on rounding off this aspect of the Oxygen Sub-Committee's work. It was obvious that one important result of the work of the Oxygen Sub-Committee was that a method—distinct from the vacuum fusion method—had been developed and checked for the accurate determination of hydrogen in steel in those cases where the total oxygen and nitrogen were not required at the same time. Whether it would be possible later on to apply it to other metals, as the author suggested, remained to be seen, but at any rate there was now a yardstick which had not existed before.

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## CORRESPONDENCE.

Mr. T. E. ROONEY (Teddington, Middlesex) wrote that he was interested to note that the author had confirmed the results obtained by Sloman,<sup>1</sup> which in turn had confirmed the earlier work of Rooney and Barr.<sup>2</sup>

The Rooney and Barr method differed from the vacuum heating method in that the hydrogen was evolved by heating the sample in nitrogen at atmospheric pressure, but the standardisation of the conditions of extraction (600° C. for 1 hr.) was the same. Unfortunately, at the time when Sloman's work was carried out the Rooney and Barr apparatus had been dismantled, so that a direct comparison of the two methods was not possible.

The author had examined a number of different types of steel, and it was interesting, therefore, to refer to the work of Inglis and Andrews,<sup>3</sup> who experimented with a mild steel and six alloy steels. From their experiments it would appear that the amount of hydrogen contained in a particular steel was not dependent on its composition but on the treatment to which it had been subjected. This raised an important point to which Sloman had already referred in the verbal discussion, namely, the loss of hydrogen from steel in the cold. There was no doubt that hydrogen could be lost in the cold from a hydrogen-treated steel, as was shown in a recent paper by Eilender, Yü Chih Chiu and Willems.<sup>4</sup>

It was possible that there was no difference in the form or state of combination in which the hydrogen occurred, but that the residual hydrogen, usually small in amount, was retained in the interior of the sample.

The author's reference to the tendency for the vacuum fusion method to give slightly higher results than the vacuum heating method might depend on the risk of contamination by grease or wax used in sealing the apparatus. This difficulty had been experienced by the writer in his earlier work and was confirmed by the results obtained by Sloman (*loc. cit.*, p. 61) on rolling pure iron in contact with oil.

Dr. N. P. ALLEN (Birmingham) wrote that Dr. Newell was to be congratulated on producing so simple a solution to a difficult problem. The agreement between his results and those obtained by the vacuum fusion method was striking and led one to the belief that the way was open for the exact investigation of questions in which hydrogen was involved.

There were hints in the paper that the author did not achieve

<sup>1</sup> Eighth Report on the Heterogeneity of Steel Ingots, *Iron and Steel Institute*, 1939, *Special Report No. 25*, Section VI., Part 2A.

<sup>2</sup> *Journal of the Iron and Steel Institute*, 1929, No. I., p. 573.

<sup>3</sup> *Journal of the Iron and Steel Institute*, 1933, No. II., p. 383.

<sup>4</sup> *Archiv für das Eisenhüttenwesen*, 1940, vol. 13, Jan., p. 309.



this result without running into many perplexities, and it might have been helpful to many who would follow his lead if he had devoted a little more space to small points of detail, such as, for example, the influence of segregation and its nature, the method of cleaning the surface of the sample, and the out-gassing cycle for the apparatus. According to some recent results by Eilender and his colleagues,<sup>1</sup> the time during which the specimen was allowed to stand at room temperature would appear to be important, for they were able to detect an evolution of hydrogen at room temperature from a variety of steels for periods up to 400 or 500 hr.

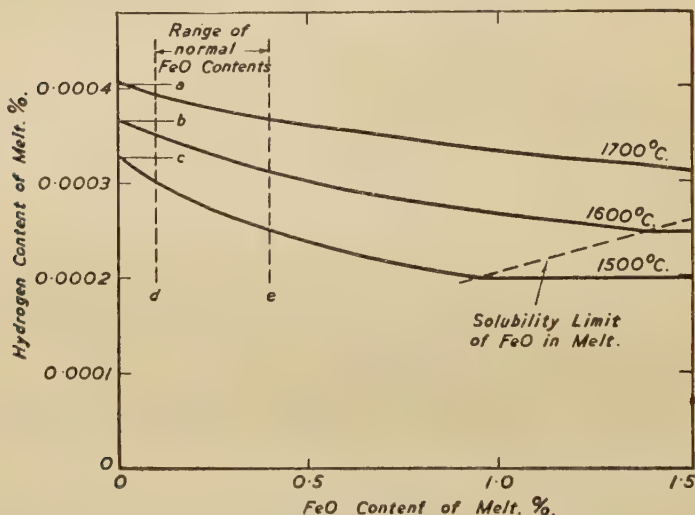


FIG. A.—Hydrogen Content of Molten Steel (assuming 15 mm. of mercury partial pressure of  $H_2O$  in vapour initially).

in some cases. Although this evolution eventually came to a complete stop, apparently the whole of the hydrogen was not removed from the metal in this process, for an equal quantity could often be obtained after further heating of the sample at the end of the process.

It had been thought worth while to try to correlate the amounts of hydrogen found in the present work with those which should have been present on the assumption that the hydrogen came from the water vapour in the melting furnace. The solubility data of Sieverts and the steam dissociation data of Chipman and Samarin had been used and the results were given in the accompanying Fig. A. The hydrogen contents to be expected were of the order of 0.0004–0.0002%, which, taking into account the loss which

<sup>1</sup> *Archiv für das Eisenhüttenwesen*, 1940, vol. 13, Jan., p. 309.

probably occurred during solidification and cooling, was in fair agreement with the quantities which had been found.

From Fig. 3 of the paper it was possible to obtain some idea of the rate of diffusion of hydrogen in steel and to compare the results with the diffusion data of other observers. The comparison was necessarily very approximate and yielded the following result :

*Diffusion of Hydrogen in Steel.*

Temperature, ° C.	Newell. G. per sec. passing through 1 sq. cm. surface under hydrogen concentration gradient of 1% (by weight) per cm.	Borelius and Lindblom. <sup>1</sup>
500	$7.4 \times 10^{-5}$	$4.8 \times 10^{-5}$
600	$10.7 \times 10^{-5}$	$10.0 \times 10^{-5}$
700	$13.5 \times 10^{-5}$	$18.2 \times 10^{-5}$

These figures were of the same order of magnitude, which spoke for the essential accuracy of the present work, but the variation of the rates of diffusion with temperature shown by Borelius and Lindblom was sharper than that suggested by the present work. Incidentally, the decrease in the rate of evolution of hydrogen resulting from the change from the  $\alpha$  to the  $\gamma$  state, which was shown in the curves in Fig. 3, had also been observed by Ham,<sup>2</sup> who noted a very pronounced drop of the diffusion constant of hydrogen through iron at the point where the  $\alpha$ - $\gamma$  change took place.

The rate of diffusion was important in connection with the hydrogen theory of hair-line cracks. It would be expected that the rate of escape of hydrogen would be roughly proportional to the inverse square of the size of the section, so that if (as Fig. 3 suggested) it took between 10 and 40 min. for all the hydrogen to escape from a  $\frac{1}{2}$ -in. round at temperatures between 700° and 500° C., it would take between 1440 and 5760 min. (1-4 days) for the hydrogen to escape from a 6-in. round under similar conditions. These times were longer than were commonly required to render masses of this size free from hair-line cracks; perhaps Dr. Newell had some comment to make on this aspect of his work.

Unfortunately the composition of the steel in Fig. 3 was not stated. It would have been of interest if the author had given some results on the effect of composition on the rate of escape of the hydrogen, for it seemed fairly clear that the rate of cooling necessary to avoid hair-line cracks was much dependent on the composition of the steel, and since the hydrogen contents were much the same in all cases, some difference in the rate of escape was required if the hydrogen theory of hair-line cracks was to be accepted in its simple form. It was gathered from the remark on p. 253 that striking differences in the rate of escape of hydrogen

<sup>1</sup> Smithell, "Gases in Metals," p. 89. London, 1937: Chapman and Hall.

<sup>2</sup> Ham, *Transactions of the American Society for Metals*, 1937, vol. 25, June, p. 536.

were not observed, except in certain peculiar cases, and if Dr. Newell was able to confirm this, some other cause would have to be found for the differences in flake sensitivity of the typical plain carbon steel and the typical alloy steel.

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### AUTHOR'S REPLY.

Dr. W. C. NEWELL, in replying to the discussion, said that Dr. Binnie had referred to differences in the hydrogen content of certain nickel steels given in Table I. The samples chosen for comparison were simply those which were readily available at the time. They had had various treatments, some of them having been heated and forged, so that no close comparison should be made of the figures from the different steels. Precisely similar treatments would have to be given to the various steels before their hydrogen contents could be so closely compared. The figures were essentially for a comparison of the two methods.

There were various explanations of the kinks in the curves shown for the rate of hydrogen evolution above 700° C. All workers who had estimated hydrogen solubility in pure iron had found a marked increase in the solubility in the face-centred cubic or  $\gamma$  phase as compared with the other phases. On passing through the  $A_1$  transition point one would therefore expect a change in the hydrogen solubility, which, on a heating operation as conducted in the determinations, would result in an increase in the solubility and a consequent decrease in the rate at which the hydrogen was given off. He thought that the matter would require very careful consideration before any conclusions were drawn as to the effect of composition.

With regard to Mr. Whiteley's remarks upon the diffusion of hydrogen through steel, it was generally believed that monatomic hydrogen diffused through iron, since there was good evidence that in the preliminary process of adsorption there was dissociation of the diatomic molecules. Such processes would be reversible, so that in the course of the determination by the vacuum heating method any hydrogen present in cavities should be extracted and estimated.

The author certainly did not have the opportunity of examining material with numerous heavy inclusions, but he thought that Mr. Whiteley's own work<sup>1</sup> had shown that any interaction with hydrogen would be extremely slow.

As to Mr. Sloman's remarks about aluminium alloys, Dr. Newell said he had indicated in the paper that he had not done as much work with these alloys as with steel. He was interested in the gas content of aluminium alloys, but had not as yet made any comprehensive study of the rates of evolution of the gas from them. As far

<sup>1</sup> *Journal of the Iron and Steel Institute*, 1920, No. II., p. 143.

as the composition of the gas evolved was concerned, it had not been all hydrogen and a small amount of other gases had been observed. The method by which the hydrogen was determined was given in the paper.

The figures in Table I., to which Mr. Sloman made reference, were the figures he had obtained before. He had gone through them and corrected them back so that the last figure was either 0 or 5.

With regard to the loss of hydrogen from steel maintained at room temperature, that was part of the work he had in hand. The rate of evolution was very much smaller, but was definitely measurable owing to the high accuracy of the apparatus. He hoped at some subsequent date to be able to give full details of the rates of elimination of hydrogen from steel at temperatures below 400° C.

Replying to the correspondence, Dr. Newell wrote that it was highly satisfactory that this work was in agreement with that of other workers, especially in view of the fact that the accuracy of the estimations was so much higher than that previously obtainable. It was stated by Rooney and Barr that their method was very sensitive, "as it is possible to detect 0.5 ml. of hydrogen," although no figures were given of any determinations made. Problems of the day demanded a far greater accuracy, and that of the method described in the paper was a thousand times greater than that of the Rooney and Barr method.

Mr. Rooney's suggestion that the vacuum fusion method might tend to give high figures as a result of the cracking of traces of grease or wax in the samples was an interesting one. For cold-rolled sheet and strip it would seem to be particularly applicable, but for castings and forgings scarcely so.

The author thanked Dr. Allen for the detailed study he had given the paper and for the comparison made of the results with those of other workers. Certainly the work had involved at times much difficulty and perplexity, and the paper was but a brief statement of the author's conclusions from it all.

The question of the evolution of hydrogen from steel at room temperature had already been dealt with in reply to Mr. Sloman.

The conclusions drawn from the solubility data of Sieverts and the steam dissociation data of Chipman and Samarin were left in doubt by the unjustified assumption as to the "range of normal FeO contents." The range was higher than that possible for steel, as judged from numerous determinations of the oxygen content of steel made by the author.

The effect of heating steel to a temperature of, say, 600° C. was to increase not only the rate of diffusion but also the solubility of hydrogen in steel. The possible outcome of such a heating was therefore not only a loss of hydrogen but also a redistribution of it, and any hydrogen hair-line crack theory must take this into account.

The composition of the steel in Fig. 3 was 3.5% of nickel, 0.3% of carbon. No striking differences were observed in the rates of hydrogen evolution for different types of steel, but Dr. Allen when drawing any conclusions from this observation should take cognisance of the effect of composition upon the solubility of hydrogen as well as of its rate of diffusion.

Much more work was indicated as desirable.



# ANTI-PIPING COMPOUNDS AND THEIR INFLUENCE ON MAJOR SEGREGATION IN STEEL INGOTS.<sup>1</sup>

By E. GREGORY, Ph.D., M.Sc., F.I.C. (ROTHERHAM).

(Figs. 6 to 13 = Plates VIII. to XV.)

*Paper No. 1/1940 of the Committee on the Heterogeneity of Steel Ingots.*

## SUMMARY.

Experimental evidence has been given to show that delayed freezing of the molten steel in the feeder-head produced by the application of anti-piping compounds and after-teeming, exerts a marked influence on the extent and position of the major segregate in the ingot. The view is expressed that major segregation in steel is a consequence of the initial separation of the homogeneous liquid metal into two liquid phases, followed by an enrichment of one or even both of the liquid conjugates as freezing or solidification progresses.

### *Influence of Anti-Piping Compounds on Primary Pipe.*

DURING recent years, synthetic compounds have been developed with the object of decreasing the extent of the "primary" pipe in "killed" steel ingots. As is well known, the formation of a contraction cavity, technically described as a "pipe," in an ingot of fully killed steel is inevitable, since it is a natural consequence of the fact that the density of the liquid metal is less than that of the solid, *i.e.*, a marked contraction in volume occurs during solidification. The shape and extent of the pipe depend upon such factors as the shape of the mould, the casting temperature and the chemical composition of the steel. Higher carbon steels pipe to a greater extent than those of lower carbon contents, and the elements commonly employed as deoxidisers, notably silicon and aluminium, tend to exaggerate the volume change that occurs during freezing, and thus lead to a more extensive pipe. High teeming temperatures also tend to exaggerate the length of the pipe.

When ingots are cast with the narrow end upwards, the primary pipe may extend a considerable distance into the body of the ingot and there is a grave risk of the formation of a "secondary" pipe lower down the ingot. In ingots cast with the wide end upwards the primary pipe is more squat, *i.e.*, it does not extend so far into the ingot and there is less risk of the formation of a secondary pipe.

<sup>1</sup> Received August 4, 1939.

Fully-killed steels are generally cast with the wide end upwards. Feeder-heads, lined with some suitable refractory material, are placed on the tops of the moulds with the sole idea of decreasing the extent of the primary pipe. The lower thermal conductivity of the refractory lining of the feeder-head, compared with that of the cast-iron mould walls, serves to maintain the steel in a molten condition in the feeder-head for a considerably longer time than that in the mould. By this means, a reservoir of molten steel is maintained in the feeder-head, which serves to fill the contraction cavity that would otherwise be formed in the ingot. The object, therefore, is to confine the pipe within the feeder-head and thus to increase the proportion of

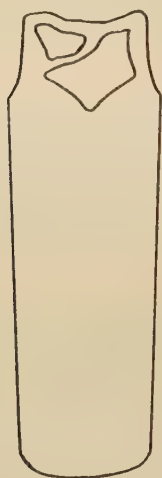


FIG. 1.—Contraction Cavity in an Untreated Steel Ingot.

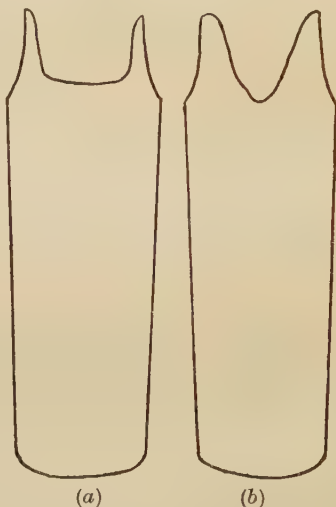


FIG. 2.—Contraction Cavities in Ingots Treated with Anti-Piping Compound. (a) Ideal ; (b) more usual form.

usable material. Even under the best conditions, however, the surface of the metal in the head freezes shortly after casting, forming a “bridge” above the molten steel beneath it. The contraction cavity subsequently formed is usually divided in the manner indicated in Fig. 1, and in some cases, unfortunately, the pipe may extend into the body of the ingot, a difficulty which normally can only be overcome by using a deep feeder-head of proper design.

These difficulties are certainly real when using feeder-heads of normal height and shape, and have been mainly responsible for the development of the so-called “anti-piping” compounds. The main object of using these compounds has been to confine the primary pipe within the feeder-head and so to increase the proportion of useful material. Matuscha<sup>1</sup> has previously shown that these

<sup>1</sup> *Journal of the Iron and Steel Institute*, 1938, No. I., 109 P.

compounds exert a marked effect on the shape and disposition of the pipe. The term "anti-piping" is somewhat unfortunate and to some extent is misleading since, as already stated, pipe cannot be avoided in killed steels, as it is a natural consequence of the contraction that occurs during freezing. By means of these compounds, which are added in the form of powder to the surface of the molten metal in the feeder-head immediately after casting, a reservoir of liquid steel is maintained in the head for a much more extended period. The result is the formation of an "open" pipe (*i.e.*, there is no bridging) in the feeder-head, as represented in Fig. 2. The section indicated in Fig. 2 (a) represents the ideal case where the primary pipe consists essentially of a hollow shell. More often, however, the pipe takes the form of a hollow cone, as represented in Fig. 2 (b), in which case there is a greater possibility of the pipe extending into the body of the ingot.

The chemical compositions of the different proprietary anti-piping compounds differ considerably, as is evident from Table I.

TABLE I.—*Compositions of Proprietary Anti-Piping Compounds.*

Number:	1.	2.	3.	4.	5.
Al <sub>2</sub> O <sub>3</sub> . % . . .	41.65	62.20	7.56	13.43	13.09
SiO <sub>2</sub> . % . . .	4.59	18.20	22.50	22.10	18.60
Fe <sub>2</sub> O <sub>3</sub> . % . . .	2.52	2.60	3.50	6.10	1.71
CaO. % . . .	2.09	3.50	...	0.80	...
MnO. % . . .	0.17	...	0.44	...	0.09
MnO <sub>2</sub> . % . . .	...	...	...	...	...
Na <sub>2</sub> O. % . . .	4.24	...	} 0.72	...	0.636
K <sub>2</sub> O. % . . .	...	...		...	
CO <sub>2</sub> . % . . .	6.02	...	...	...	...
Mg. % . . .	...	...	...	...	0.52
MgO. % . . .	0.52	2.89	0.21	0.65	0.23
CuO. % . . .	...	1.20	...	...	...
NaCl. % . . .	...	2.18	...	...	...
KCl. % . . .	...	0.36	...	...	...
Carbonaceous matter. %	21.33	6.80	59.56	48.17	60.45
Volatile matter. % .	...	...	...	8.50	...
Loss on ignition. % .	...	...	...	56.82	63.50

Generally, therefore, these compounds consist essentially of mixtures of carbonaceous matter and irreducible oxides. When placed on the surface of the molten steel the carbon and any other elements present slowly oxidise, thereby generating heat. The non-metallic matter in the powder remains as a residue which serves to insulate the molten metal beneath. It is this combination of heat-generating and heat-insulating properties which serves to delay the freezing of the metal in the head to such a marked extent. As is well known, the old practice of covering the molten metal with hot coke had a similar object in view. The difficulty with coke was that considerable carbon absorption took place, often accompanied by an

exaggerated pipe. Earlier experiments also indicated that carbon was absorbed from the anti-piping powders by the molten metal in contact with it. With some low-carbon steels, which normally do not pipe to any marked extent, carbon absorption occurred to such an extent as to convert them, in so far as the freezing of the metal in the head was concerned, into "fully-piping" steels. Later, however, compound No. 5 was obtained and the amount of carbon pick-up was then reduced to negligible proportions, even though it is rich in carbon. This compound was exclusively employed in the experiments recorded in this paper.

The primary object of this series of experiments was to determine the extent of the piped parts of blooms rolled from ingots cast (a) in the ordinary way, (b) treated with anti-piping compounds, and (c) treated with anti-piping compound and then "after-teemed." In the latter case, the feeder-head was refilled with molten steel after several other ingots had been cast.

When using the anti-piping compound alone, a period of about 1 hr. elapsed between the casting of the ingot and the final freezing of the liquid metal surface in the head. During this period the liquid surface gradually sank to the extent of between 8 and 10 in. When both the powder and after-teeming were resorted to, the metal in the head remained molten for a period of between  $1\frac{1}{2}$  and 2 hr.

The object of after-teeming, of course, was to replenish the supply of liquid in the head and still further delay its freezing so as to obtain a shorter and more squat pipe of the type indicated in Fig. 2 (a). Generally, in regard to pipe, the anticipated results were obtained, as will be seen from the sulphur prints reproduced in Figs. 6 to 10. In each case, excepting cast C3886, the original ingot weighed 67 cwt. and the sulphur prints were taken from rolled blooms 9 in.  $\times$  9 in. in section. Each bloom was sectioned along the longitudinal axis and represented 20% by weight of the original ingot.

In each figure, (a) represents material rolled from an ingot cast with the feeder-head only; in (b) the metal in the feeder-head was treated with anti-piping compound, and in (c) the feeder-head was treated with the compound and then after-teemed. Unfortunately, there are other factors, which need not be discussed here, that preclude the general application of the combined method involving the use of anti-piping compounds and after-teeming. For certain steels, anti-piping compounds yield excellent results without the need of after-teeming; in some instances, there are definitely some disadvantages associated with the use of these powders.

#### *Treatment with Asbestos Sheet.*

Ingots were also cast and covered with asbestos sheet instead of the anti-piping compound in order to delay the freezing of the steel in the head. Even though only  $\frac{1}{8}$  in. in thickness, the asbestos was



effective enough to permit of after-teeming, but the results obtained, although an improvement on the ordinary method of casting, were not quite so satisfactory as might have been expected. The extent of the pipe was generally less, but bridging almost invariably took place. Typical sulphur prints are shown in Figs. 11, 12 and 13, where (a) was untreated, (b) covered with asbestos and (c) covered with asbestos and after-teemed.

### *Influence of Delayed Freezing on Major Segregation.*

The main object of presenting this paper is to draw attention to the influence of delayed freezing of the metal in the head on the position of the major segregates.

An examination of the sulphur prints reproduced in Figs. 6 to 10 clearly shows that the zones richest in impurities are nearest the top in the ingots treated with anti-piping compound and after-teemed, and occupy the lowest positions in ingots not treated in any way. Generally, too, the segregated zone does not extend so far, *i.e.*, is much less elongated in the treated ingots than are after-teemed.

In order to determine the magnitude of the major segregation, drillings were taken from blooms rolled from casts H456 and E2216 at positions indicated in Fig. 3 (a). The analyses of the drillings are indicated in Figs. 3 (b, c, d) and 4, and it will be seen that there is a really astounding concentration of the impurities sulphur, phosphorus, carbon and manganese in the middle positions of the major segregates.

In the "asbestos" series, similar results were obtained, as indicated in Fig. 5, showing the results of analysis of the bloom from cast C3886. The segregated zones, however, were considerably less rich in impurities, as might be expected from the fact that the freezing of the liquid metal in the head was not nearly so much delayed.

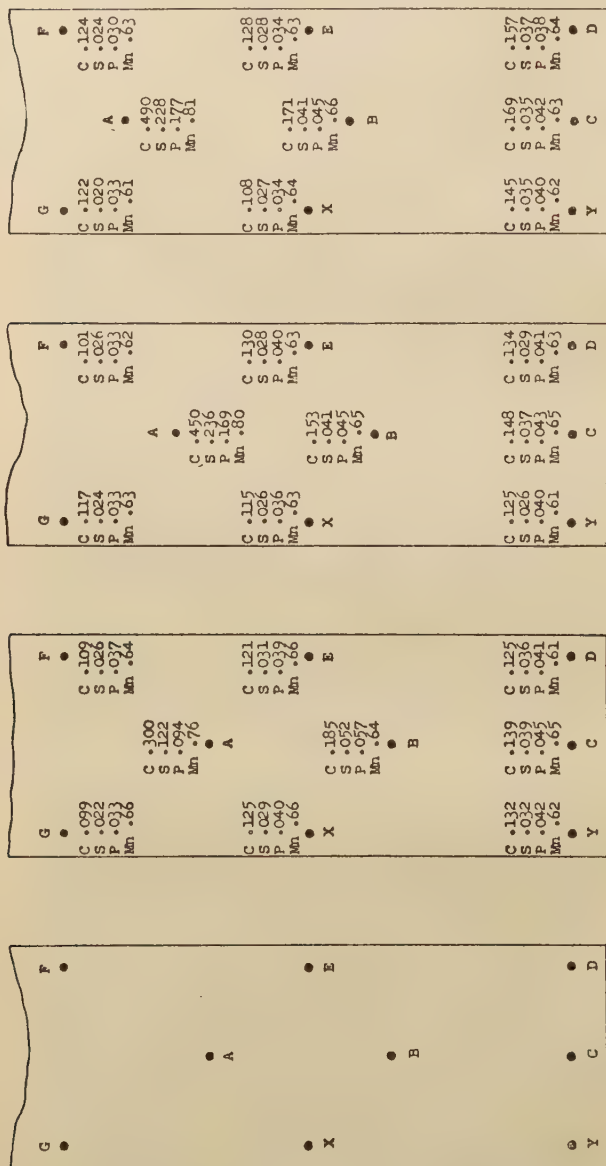
It will be noted also that in the asbestos-treated ingots, the segregated zones are more elongated and not so clearly defined, even when after-teemed. A noteworthy feature is that there is apparently no connection between the base of the pipe and the position of the major segregate. The above facts are significant.

### *Interpretation of Results.*

Andrew and his collaborators,<sup>1</sup> have expressed the view that major segregation in steel ingots is due to the formation of an immiscible liquid complex, rich in sulphur, phosphorus and other impurities. In the discussion of Andrew's paper, the present author considered this view to be too extreme and suggested that a basic cause of major segregation may be the formation of a *partially* miscible liquid complex. On this basis, molten steel may be re-

<sup>1</sup> Eighth Report on the Heterogeneity of Steel Ingots, Section II., *Iron and Steel Institute*, 1939, *Special Report No. 25*, p. 1.





(a) *A* = centre of segregate. *B* = midway between *A* and *C*. *C* = middle of bloom corresponding to 20% from the top of the original ingot. *D* and *Y* = 1 in. from corresponding sides in same transverse plane as *C*. *E* and *X* = positions corresponding to 10% from the top of the original ingot and 1 in. from the sides. *G* and *F* = 9 in. from the top and 1 in. from the sides.

(b) Ordinary feeder-head.

(c) Feeder-head treated with anti-piping compound and then after-teamed.

(d) Feeder-head treated with anti-piping compound and then after-teamed. Cast analysis: Carbon 0.155%; silicon 0.103%; sulphur 0.030%; phosphorus 0.040%; manganese 0.68%.

garded as an emulsion of two conjugate liquid solutions, one much richer in impurities than the other, which tend to separate on prolonged standing in the ladle or moulds. The prevailing conditions prior to the commencement of freezing are thus comparable with those during the separation of a homogeneous solution of, say, phenol in water into two conjugate liquid solutions. When a clear and fairly concentrated solution of phenol in water is rapidly cooled a "cloudy" emulsion is obtained consisting of a saturated solution of phenol in water and a saturated solution of water in phenol. On standing, these solutions gradually separate into two distinct layers, the particles of the one possessing the greater density moving downwards and the other upwards. On standing, therefore, a clear liquid forms at the top and another at the bottom, separated by a cloudy layer which slowly diminishes in depth until eventually it disappears entirely and two clear liquids, one upon the other, are obtained.

During the cooling of liquid steel, the conditions are not so simple. Almost immediately after the molten metal is poured into the mould, freezing occurs and the columnar crystals subsequently formed must necessarily impede the upward and downward movements of the two liquid conjugates. If the rate of rise and coalescence of the particles of the conjugate rich in impurities is much less than the rate of freezing, the impurities will be spread over a wide area. On the other hand, if freezing is delayed there is a far better chance of coalescence and the rising of the coalesced particles towards the upper part of the ingot.

Objection may be raised to this view on the grounds that there should be a marked line of demarcation between the microstructures of the segregated zone and the rest of the ingot, but this view may be discounted by the perfectly legitimate assumption that complete separation of the two conjugates into two liquid layers is never likely to occur in actual practice. Unfortunately, the problem cannot be completely and satisfactorily explained by reference to thermal equilibrium diagrams; the system is quaternary at least, so that any true diagrammatic representation becomes impossible. It is of interest, however, to note that the existence of two liquid conjugates has been demonstrated in the Fe-FeS-MnS,<sup>1</sup> Fe-FeS-Fe<sub>3</sub>P<sup>2</sup> and Fe-Fe<sub>3</sub>C-FeS<sup>3</sup> ternary systems. The view has also been expressed that oxygen may contribute to the formation of liquid conjugates.<sup>4</sup>

In ternary systems exhibiting a region of partial or limited miscibility in the liquid state, the actual freezing may be accompanied by an alteration in the concentrations of the two liquid conjugates. Under true equilibrium conditions, *i.e.*, with very slow

<sup>1</sup> Vogel and Bauer, *Archiv für das Eisenhüttenwesen*, 1933, vol. 6, May, pp. 495-500.

<sup>2</sup> Vogel and de Vries, *Archiv für das Eisenhüttenwesen*, 1931, vol. 4, June, pp. 613-620.

<sup>3</sup> Sato, *Technology Reports of the Tôhoku Imperial University*, 1932, vol. 10, pp. 453-493.

<sup>4</sup> Ziegler, *Revue de Métallurgie, Mémoires*, 1909, vol. 6, pp. 459-493.

rates of cooling, their concentrations gradually approach each other and eventually the residual liquid becomes homogeneous.

With quicker rates of cooling there is not enough time for equilibrium to be established, and it may then be assumed that the final liquid actually consists of two liquid phases which freeze independently. During subsequent cooling some diffusion in the solid state must occur, so that any sharp surface of demarcation that

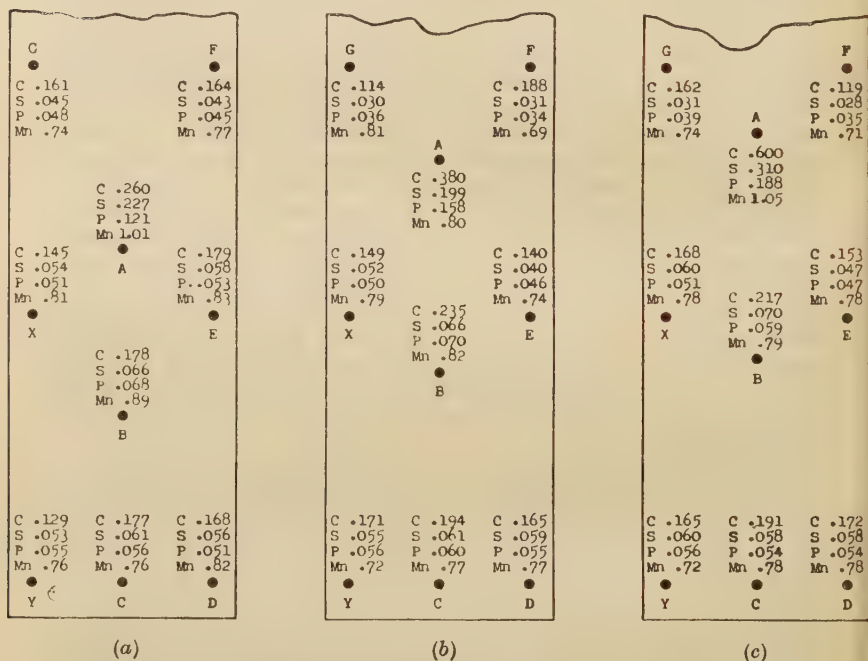


FIG. 4.—Cast E2216. Cast analysis: Carbon 0.161%; silicon 0.052%; sulphur 0.055%; phosphorus 0.053%; manganese 0.79%.

may have existed immediately after solidification of the two conjugates is masked in the final structure. When an alloy is cast into a mould with conducting walls, the rate of cooling is very rapid in the earlier stages and equilibrium conditions are not even approached.

Under ordinary conditions of cooling, ternary alloys cannot be expected to yield equilibrium structures, and with still more complex systems the departure from equilibrium will be still more marked.

As already stated, the existence of liquid conjugates in the Fe-FeS-MnS, Fe-FeS-Fe<sub>3</sub>P and Fe-Fe<sub>3</sub>C-FeS systems has been

definitely established. It seems not unreasonable to assume, therefore, that in the more complex systems containing carbon, sulphur, phosphorus, manganese, oxygen, &c., in addition to iron, there is the possibility of the separation of the initial homogeneous molten steel into liquid conjugates which together constitute an emulsion. The rate at which de-emulsification can take place will depend on the casting conditions, although complete separation

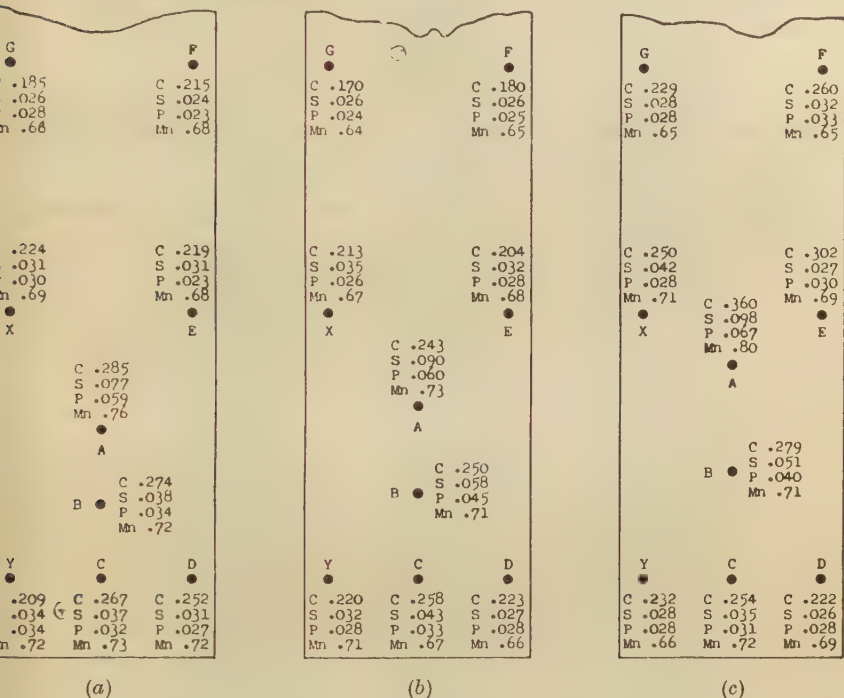


FIG. 5.—Cast C3886. Cast analysis: Carbon 0.227%; silicon 0.141%; sulphur 0.029%; phosphorus 0.024%; manganese 0.69%.

of the two liquids cannot be expected in practice. Nevertheless, by delayed freezing, there is a greater opportunity for the coalescence and separation of the particles of the conjugate liquid solutions.

Exponents of the differential freezing theory may raise objections to the above postulates. The author has no hesitation in stating that differential freezing is a fundamental cause of segregation in steel ingots but considers that differential freezing is not the com-

plete explanation, particularly in view of the remarkable degree of segregation associated with delayed freezing. Further, on the basis of this theory, the last material to freeze or solidify should be richest in impurities, so that these should be concentrated in the vicinity of the primary pipe. Careful examination of Figs. 6, 8, 11 and 12 definitely indicates that there is no real connection between the pipe and the impure zone. In the present series of experiments it was only when freezing in the head was delayed that the position of the major segregate approached the base of the primary pipe cavity.

*Acknowledgment.*

In conclusion, the author wishes to take this opportunity of expressing his thanks to his colleagues for assistance in the experimental work and to Mr. H. Williams for helpful criticisms. Particular thanks are due to Mr. F. Clements, Managing Director of the Park Gate Iron & Steel Co., Ltd., for permission to publish the results of these experiments.





FIG. 6.—Sulphur Prints of 9-in. Blooms rolled from 67-Cwt. Ingots, cast H456.  
 (a) Cast with feeder-head only. (b) Covered with anti-piping compound  
 after casting. (c) After casting, covered with anti-piping compound and  
 then after-teamed.

[Gregory.  
 [To face p. 272 P.]



(a) Ingot  
No. 5.

(b) Ingot  
No. 4.

(c) Ingot  
No. 3.

FIG. 7.—67-Cwt. Ingot, cast E2216. Cast analysis: Carbon 0.161%; silicon 0.052%; sulphur 0.055%; phosphorus 0.053%; manganese 0.79%.

[Gregory.



FIG. 8.—67-Cwt. Ingot, cast *H459*. Cast analysis: Carbon 0.070%; silicon 0.052%; sulphur 0.047%; phosphorus 0.049%; manganese 0.38%.

[Gregory.]



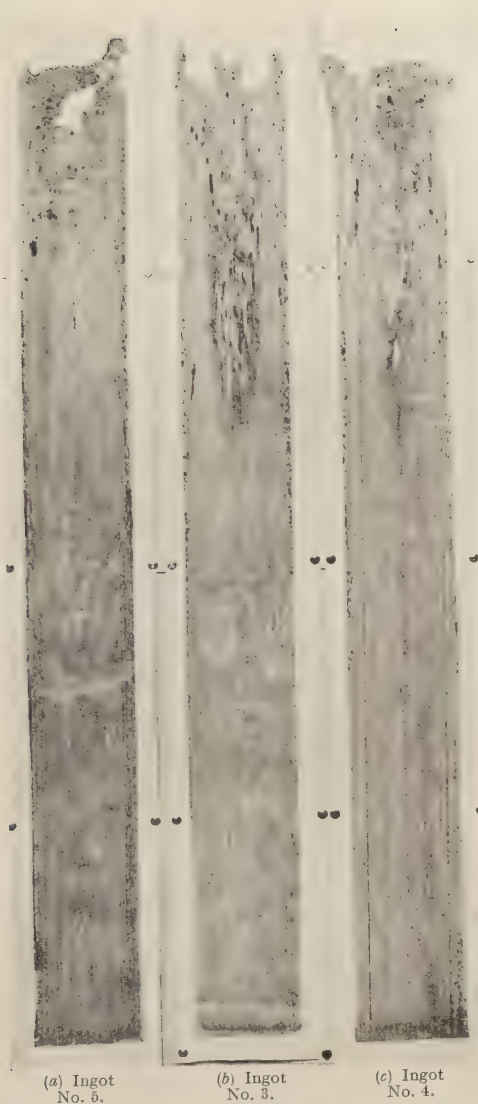
(a) Ingot  
No. 5.

(b) Ingot  
No. 3.

(c) Ingot  
No. 4.

FIG. 9.—67-Cwt. Ingot, cast *E2215*. Cast analysis: Carbon 0.130%; silicon 0.066%; sulphur 0.054%; phosphorus 0.025%; manganese 0.85%.

[Gregory.]



(a) Ingot  
No. 5.

(b) Ingot  
No. 3.

(c) Ingot  
No. 4.

FIG. 10.—67-Cwt. Ingot, cast K1180. Cast analysis: Carbon 0.170%; silicon 0.085%; sulphur 0.039%; phosphorus 0.034%; manganese 0.70%.

[Gregory.]





(a) Ingot  
No. 4.

(b) Ingot  
No. 3.

(c) Ingot  
No. 2.

FIG. 11.—67-Cwt. Ingot, cast A7837. Cast analysis : Carbon 0·300% ; silicon 0·136% ; sulphur 0·024% ; phosphorus 0·040% ; manganese 1·55%.

[Gregory.



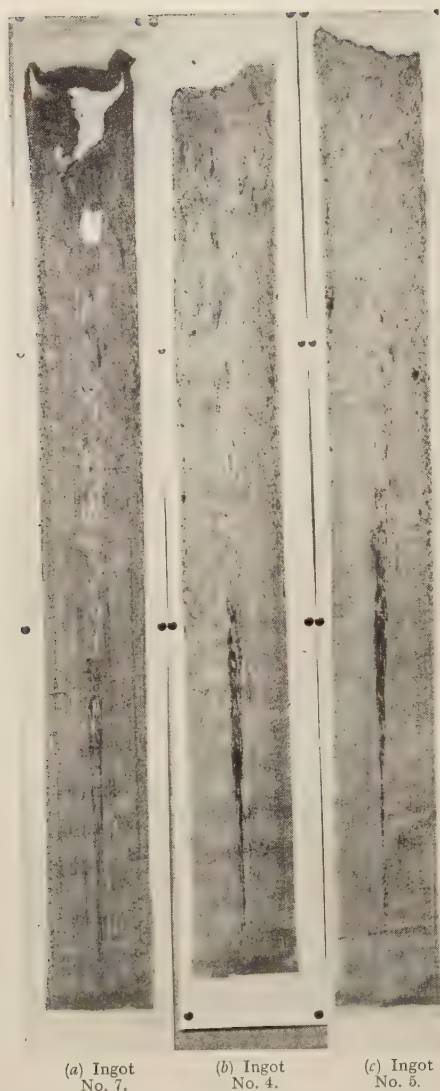
(a) Ingot  
No. 4.

(b) Ingot  
No. 2.

(c) Ingot  
No. 3.

FIG. 12.—67-Cwt. Ingot, cast A7838. Cast analysis : Carbon 0.165% ; silicon 0.080% ; sulphur 0.026% ; phosphorus 0.025% ; manganese 0.72%.

[Gregory.]



(a) Ingot  
No. 7.

(b) Ingot  
No. 4.

(c) Ingot  
No. 5.

FIG. 13.—87-Cwt. Ingot, cast C3886. Cast analysis:  
Carbon 0.227%; silicon 0.141%; sulphur 0.029%;  
phosphorus 0.024%; manganese 0.69%.

[Gregory.  
[To face p. 273 p.

## DISCUSSION.

Mr. J. H. WHITELEY (Consett, Co. Durham) said that the paper dealt with the formation and subsequent movement of segregate in steel ingots, and these were two of the main subjects of investigation by the Committee on the Heterogeneity of Steel Ingots. It was therefore a welcome contribution. On the way in which the segregate was formed the Committee were rather sharply divided. Most of the members believed that it could be entirely accounted for by the differential freezing which unquestionably took place, although none of them had, as yet, explained satisfactorily how this process brought about the peculiar distribution of the segregate observed in ingots. On the other hand, a few of the members maintained that the mode of occurrence of the segregate could not be accounted for by differential freezing and were persuaded that segregation actually began in the liquid steel, as Dr. Gregory had suggested. They held the view that before the metal began to solidify minute droplets, rich in carbon, sulphur and phosphorus, appeared, and these, being lighter than the major iron phase, tended to rise in the ingot while it slowly set in the mould.

Now, although Dr. Gregory had advanced some arguments in favour of this explanation he still apparently halted between the two opinions. That was evident from two statements made in the paper. The first occurred on p. 267 where he stated that "a basic cause of major segregation may be the formation of a partially miscible liquid complex." Yet on p. 271 Dr. Gregory said that he had "no hesitation in stating that differential freezing is a fundamental cause of segregation in steel ingots." Thus he considered one to be a "basic" and the other a "fundamental" cause and, with killed steel at any rate, it was difficult to see how these two pronouncements were to be reconciled. Immediately following the latter statement another remark appeared which seemed to indicate that Dr. Gregory had not clearly grasped the significance of his partial-miscibility explanation. He said, quite rightly, that "on the basis of this"—*i.e.*, the differential—"theory, the last material to freeze or solidify should be richest in impurities" and then continued "so that these should be concentrated in the vicinity of the primary pipe." But that was precisely what did happen. There was an unmistakable tendency for the segregate to appear near the pipe cavity. Indeed, that was one of the reasons why he (Mr. Whiteley) considered that segregation was not the result of differential freezing. Take the case of a wide-end-up ingot of killed steel weighing, say, 10 tons and cast without a feeder head. The last part of such an ingot to cool was not in the vicinity of the pipe cavity but at the centre, as could easily be seen if the ingot was stripped hot in a dark place. Hence, according to the differential freezing theory the segregate should be

found at the centre, whereas actually it occurred considerably higher up and much nearer the primary pipe.

Dr. Gregory had given several illustrations which were intended to demonstrate that anti-piping compounds, by delaying the freezing of the steel in the head, raised the segregate. Some of these illustrations brought this effect out clearly but others were not so convincing. For example, there was practically no segregate to be seen in the (a) blooms of Figs. 8 and 10, and taken by themselves it could be inferred that the use of the anti-piping compound had actually produced segregation. Without the other illustrations, especially Figs. 6 and 9, these two would be of little value, for one had to imagine the extent and position of the segregate in the (a) bloom in each case. It looked very much, therefore, as though in those instances Dr. Gregory had missed the segregate, probably because uneven reduction in cogging had shifted it away from the centre. He (Mr. Whiteley) was disposed to think that if ingots instead of blooms had been sectioned a more satisfactory result would have been obtained. He would also point out that the whole of the work had been done on incompletely killed steels, and it was a well-known fact that evolved gases could move segregate about to a considerable extent. Consequently a second disturbing factor had been present. Yet, notwithstanding these two objections to the method employed, he thought the observations on the effect of anti-piping compounds were substantially correct, since they were quite in line with other work which had been published by the Committee.

When examining the series of analyses which Dr. Gregory had given in Figs. 3, 4 and 5 he (Mr. Whiteley) had obtained the ratios of the increase of manganese to that of sulphur along the axes on which the points CBA were placed. For instance, in Fig. 3 (b) the manganese increment was 0.11% and the maximum difference in sulphur was 0.083%, which gave a ratio of 1.32. He had found that although each set of three blooms had been made from the same steel the ratios varied considerably, as shown below :

*Ratio of Manganese Increment to Sulphur Increment.*

Fig. 3 (b)	.	.	1.32	Fig. 4 (b)	.	.	1.5
(c)	.	.	0.75	(c)	.	.	0.22
(d)	.	.	0.93	(d)	.	.	1.07

Further, it would be seen that, in both cases, a sharp drop occurred when the anti-piping compound was used and then there was a partial recovery in the ingots which were after-teemed. This rise might be the result of the addition of fresh metal. The ratios for the ingots represented in Fig. 5, however, did not change in this way. There the ratio increased from 0.75 in bloom (a) to 1.27 in the other two where asbestos sheet had been used. This fact might be connected with the use of asbestos, for, judging by the sulphur prints reproduced in Figs. 11, 12 and 13, this material did not



seem to have had the same effect on the segregates as the anti-piping compound. Indeed, Dr. Gregory remarked that it was less satisfactory in its action. Certainly the segregation as indicated in Fig. 5 was much less intense than that in Figs. 3 and 4.

With regard to the similar way in which the ratios changed in the other two sets of analyses (Figs. 3 and 4) three possible explanations could be suggested. In the first place there was a remote chance that the manganese estimations were incorrect. Although, for the sake of completeness, this possibility could not be excluded, he (Mr. Whiteley) felt that errors of the magnitude entailed were extremely unlikely. At the same time he would ask Dr. Gregory whether he was quite satisfied that the figure for manganese given at position *A* in Fig. 4 (*b*), *viz.*, 0.80%, was correct. At position *C* it was 0.77%, and considering the extent of the segregation there shown he (Mr. Whiteley) would have expected the manganese to have risen much more than 0.03%. Again, in Fig. 4 (*a*) 0.89% was shown at position *B*, whereas at position *C* 0.76% was found, while the amounts of carbon, sulphur and phosphorus were practically the same at the two points. That variation was particularly difficult to understand. Another possible explanation of the similarity between the ratio changes in Figs. 3 and 4 could be that it was merely a coincidence. If that was not the case then only one other explanation remained, which was that some factor had been at work of which we were at present ignorant. The variations which occurred in the manganese increments undoubtedly presented a difficult problem, and to solve it completely much further work would be needed.

Dr. W. H. HATFIELD, F.R.S. (Vice-President, Sheffield), said it was very good of the Park Gate Company to permit the publication of the information contained in the paper.

In presenting it the author had put forward the water and phenol diagram as a strong argument in favour of his theoretical interpretation of the results. He gave an interesting practical treatment of the effect of anti-piping compounds and then discussed the theoretical phases of the subject without bringing forward a shred of new evidence from practical experiment; that seemed wrong from a discussion point of view.

Personally, he held definitely that the fundamental influence in producing segregation was differential freezing, and he confessed that at the moment he saw no evidence which justified one in getting away from that position. He did not think that anyone who had considered the idea of the separation of two liquid phases had as yet brought forward any conclusive evidence.

It was desirable to emphasise the difficulty of the subject. Mr. Whiteley pointed to the hottest spot in the ingot, but had no evidence that it was so.

Mr. J. H. WHITELEY : My eyesight.

Dr. HATFIELD replied that that was no good. By looking at the outside of the ingot, Mr. Whiteley sought to draw conclusions as to a position in the interior of the ingot. It was impossible to do that. One of the biggest problems which the Ingot Committee had had to consider was how to determine the temperature gradient throughout the ingot. Mr. Lightfoot had been working on that from a mathematical point of view because there was no means of carrying out the experiment, and they did not know the temperature distribution in an ingot during freezing. There was, however, some evidence which the author seemed to have forgotten. Mr. Talbot many years ago had rolled ingots immediately after casting, or after a critical period of time; liquid came out of the end of the ingot; that liquid was the last to freeze, and was the segregate, entirely in conformity with the differential freezing theory.

The Ingot Committee had made a start with the collective study of ingots seventeen years ago; at the commencement they were very elementary in their methods. Even in the present paper the author used a drill of which the diameter was not stated——

The AUTHOR, interposing, said it was about  $\frac{1}{4}$  in. in dia.

Dr. HATFIELD said that was a big area. The author drilled a mass with it, and the result was very empirical; it did not really give a proper conception of the intrinsic variations in composition throughout the ingot. At present Dr. Desch was tackling the question of micro-analysis and more discriminating attempts to find out what was the real distribution of the elements. Until an advance had been made in the technique of exploring the differential composition which actually occurred it was not possible to come to final results. It was curious, but nothing had been heard that morning, and he did not suppose anything would be, of one idea formerly very prevalent as regards the heterogeneity of ingots, namely, the falling crystal idea. That had entirely gone by the board.

Mr. J. H. WHITELEY said he could not agree with Dr. Hatfield's statement that it was impossible to locate the last part of the interior of the ingot to cool by visual examination. It was true that the temperature gradient and therefore the rate of cooling were not known with certainty, but he (Mr. Whiteley) failed to see how that invalidated his contention that the hottest part could be directly observed. Nor could he see how Mr. Talbot's experiments could be regarded as supporting the differential freezing theory. In whichever way the segregate was formed it could be moved about in a semi-set ingot.

Dr. D. BINNIE (Irlam, near Manchester) said he did not like to draw conclusions concerning ingots from rolled blooms. If one looked at any ingot, particulars of which had been published by the Ingot Committee, one would find that the sulphur segregate was always right up against the pipe cavity, but in the author's rolled blooms they were separated. The segregated part was more plastic and could, of course, move about, and might thus give rise to wrong conclusions as to the original position of the segregate in the ingot.

From an industrial point of view he failed to see any evidence for the immiscibility theory. Free-cutting steel very high in sulphur, for instance, when analysed would be found to be very uniform; the sulphur at the top, apart from the feeder head, agreeing very closely with that at the bottom. If it were separating into immiscible layers some evidence should be there.

The question of phenol interested him, but he wondered whether the concentrations of sulphur and phosphorus in the ingot were sufficient to bring in the author's analogy. Was 0.029% of sulphur a supersaturated solution of sulphur in steel?

Not long ago a ladle of steel had been held up for over an hour, and all the ingots were examined to study the effect of this extra time in the ladle. The last ingot was just as homogeneous and also had the same analysis as the first, and that was after standing up for an extra hour, which was the same length of time as that during which the final freezing of the metal in the ingot head was delayed by the anti-piping compound.

Dr. C. H. DESCH, F.R.S. (Vice-President, London) said that the author had argued his case very well, but left him completely unconvinced. To speak, as the author did, of Professor Andrew's view being that a completely immiscible phase was formed did not seem to be quite fair; personally, he did not think that anyone had suggested that such immiscibility as occurred with water and mercury was ever found in steel. They had pictured the case, if it ever did occur, as being on a par with the water-phenol system, which was always quoted in the text-books. It was known that an immiscible complex did form containing sulphur, oxygen, iron and manganese, and that tended to rise, being light, and was found in the form of inclusions; but he had never seen any evidence which convinced him that that complex contained appreciable quantities of either carbon or phosphorus. The author had referred to the fact that actual immiscible phases did occur in the iron-copper system and in the iron-carbon-phosphorus systems, for example, but they occurred only at concentrations which were far outside the concentrations met with in commercial steels, and personally he did not think that they had any influence. His own view was that the structures in question could be completely interpreted on the principle of differential freezing, always remembering that

that complex was formed containing those particular elements—really the sulphide-oxide complex.

He was not convinced by the distribution of the impurities shown in the blooms dealt with by the author, for reasons stated by others in the discussion. After all, the liquid towards the end of the freezing had been very much pushed about, partly by the anti-piping compounds, partly by the movement of gases and partly by the forging of the ingot down to a bloom. If the evidence accumulated by the Ingot Committee were examined, it would be found, he thought, that the differential freezing, plus the well-known liquid complex formed, would account for everything.

Dr. L. F. C. NORTHCOTT (London) said there was one point which he would like to raise in favour of differential solidification and against the phenol theory. What the author had said about the phenol-water equilibrium was quite correct, but personally he thought that it had nothing whatever to do with the solidification of steel. He had been working recently not only on steel but on a number of non-ferrous alloys, essentially copper alloys with additions of a large number of other non-ferrous metals, and, with the exception of copper-iron, which was one system with which he did not deal, in none of those alloys had there ever been put forward any suggestion of liquid immiscibility; and yet the order of segregation which had been found in those ingots was quite comparable with that found in steel by the author with reference to sulphur and phosphorus, and the explanation of such segregation must be on a theory of differential solidification without any question of the two liquid immiscible-phases coming into it at all.

The PRESIDENT (Mr. John Craig) remarked that if the author had not solved the problem he had at any rate indicated that there were lines along which information might be sought. If there were any young men who could solve the problem they would deserve well of the industry and would render a great service to the world at large, because segregation in the ingot was held to be responsible for a great many troubles, and probably covered a great many defects about which little was known, although metallurgists might appear wise when called on to explain them.

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### CORRESPONDENCE.

Dr. T. SWINDEN (Member of Council, Stocksbridge, near Sheffield) wrote that Dr. Gregory had performed a very useful service in drawing attention to the utility of anti-piping compounds and had made an interesting contribution to the theoretical aspects of their use.



The idea was, of course, a very old one and its application world-wide. In his own case, some twenty-five or thirty years ago, it had been common practice to use ashes, a practice that was not entirely satisfactory. The anti-piping qualities were irregular, and from time to time there was serious trouble on account of carburisation. This had been followed by such material as boiler flue dust, to which various compounds were added with the idea of generating more heat. Excellent results were obtained from coke resulting from the carbonisation of a very high-ash coal (35–40%).

To-day, the manufacture of anti-piping compounds was a highly specialised business. There were two main functions, as stated by the author, namely, heat insulation of the surface of the ingot head, which the writer would regard as the primary function, and the generation of heat as a secondary function. One essential feature of the proprietary compounds illustrated by the author was the fine state of division of the material and also the particular nature of the carbonaceous matter. In the writer's own tests of these materials (and he believed that he had tested every type that had become available) it had been considered essential to record, in addition to the analysis, an accurate statement of the particle size and to make tests on the speed of burning under given conditions.

He confirmed Dr. Gregory's statement that, given care and common sense in their use, the value of anti-piping compounds was beyond question, but that, as he indicated, there were certain precautions to be taken if the disadvantage of central inclusions or carburisation were to be avoided. There would be others who wished to dwell upon the point made by Dr. Gregory that this work supported the view that there might be a separation in the molten steel of liquid conjugates of dissimilar composition which at least contributed to segregation effects which were so well-known. Dr. Gregory put his case very reasonably and accepted the view that differential freezing was a fundamental cause of segregation, and therefore perhaps his advocacy of the contributory effect of liquid segregation would be accepted. The writer would only wish to question one point, *viz.*, on p. 272 it was stated that on the basis of differential freezing the last material to freeze or solidify should be the richest in impurities, so that these should be concentrated in the vicinity of the primary pipe. One wondered whether the last statement was necessarily correct. It seemed to the writer that the evidence put forward, which was in line with common practice, namely, that there was a certain weight of metal above the major primary segregate which was purer than the latter, was due to the fact that this did solidify before the material somewhat lower down the ingot where the major segregate occurred.

Mr. A. C. HARRIS (Napuria, Bengal, India) wrote that he could



confirm the marked effect of anti-piping compounds in the raising of the position of the major segregate; in fact, this might well be considered to be the principal benefit derived from such treatment, even more so than the effect on piping. The latter was, without treatment, usually confined to the head but not always so the segregate. When, however, suitable anti-piping compounds were used, the normal crop in the mill, taken at the junction of the head and body, could be regarded almost invariably as a safe removal of pipe and segregation.

As Dr. Gregory was probably aware, the makers of some of these compounds recommended them even for ingots without heads in order to minimise piping, and also the coating of the inner wall of the mould for a short distance from the top with paste made from similar material. The writer had never achieved any success in this direction, but he would like to know Dr. Gregory's experience or opinion of such compromising measures. With feeder heads plus after-teeming, however, it had been found quite feasible to use a smaller amount of "head" than in normal practice and still be "clear" at the junction of head and body, thereby increasing the mill yield.

Turning to the theoretical aspect of the mechanism of freezing, the writer would like to draw attention to one or two points which appeared to reflect on Dr. Gregory's theory of two partially immiscible liquids of different concentrations. The author in his paper omitted any reference to positions *G* and *F* in the sections which he drilled for analysis. In every case illustrated these positions, while showing only minor variations in the carbon and manganese content from that found at *Y*, *C* and *D* (which might presumably be taken as representing the general average analysis of the ingot), gave markedly lower figures for sulphur and phosphorus. These, in fact, were lower than one would expect to find in the purest zone of the ingot, say, at the peak of the basal pyramid. Granted that one often found a zone of major segregation surrounded by one of inverse segregation as a balance, how, in the light of the theory of two liquids of different concentrations and density, one tending to rise and the other to fall, could this zone of extreme purity be explained at the topmost portion of the ingot?

It could not be said that this was just a matter of the first metal to freeze in pure columnar crystals, for, particularly with after-teeming, this portion was one of the last to freeze. An analysis at a point midway between *G* and *F* might prove instructive, but, judging from the reproductions of sulphur prints, this would not show any marked increase in impurities.

Dr. Gregory stated (p. 266) that with compound No. 5 the amount of carbon pick-up was reduced to negligible proportions, but how could this be satisfactorily determined? The segregation shown was truly "astounding" (p. 267) and one would almost suggest that the carbon content, increased by about 50% in the case of an

ordinary feeder-head and asbestos-covered, but by something in the neighbourhood of 300% in treated ingots, might well have been directly affected by the compound.

It would be instructive to continue the work using an ingot of higher initial carbon content, say, 0.6%.

Dr. H. O'NEILL (Derby) wrote that, as an alternative to charcoal, he had tried various proprietary anti-piping compounds with the object of facilitating the feeding of steel castings. So far no outstanding improvement had been observed. The composition of two of them was as follows :

					X.	Y.
Moisture.	%	.	.	.	1.7	2.2
Combined water.	%	.	.	.	2.1	1.7
Carbon.	%	.	.	.	11.7	12.4
Aluminium.	%	.	.	.	15.1	4.2
Alumina.	%	.	.	.	56.7	47.1
Iron oxide.	%	.	.	.	4.2	4.2
Silica.	%	.	.	.	4.2	24.5
Copper oxide.	%	.	.	.	0.3	0.2
Undetermined *	(by diff.).	%	.	.	4.0	3.5

\* Containing small quantities of lime, magnesia and alkalies.

These analyses differed from those given by the author, in that they indicated notable amounts of free aluminium, presumably intended to promote a mild thermite reaction.

Some time ago an alloy was placed on the market for making silicon additions to molten cast iron, and it was claimed that a reaction occurred which increased the temperature of the metal. Experiment failed to justify this claim.

Dr. S. A. MAIN (Sheffield) wrote that he thought the author need not be disturbed by the fact that the main segregate did not coincide with the pipe in the ingots examined. The position of the pipe was determined mainly by the location of the last material to freeze, and that of the main segregate by the highest position to which it could rise while the steel was still fluid. In ingots narrow-end-up and without a feeder-head, such as cooled off more rapidly at their upper end than at their centre, the pipe was forced downwards, but the segregate nevertheless had time to rise into the upper half before the pipe was formed.

Thus, far from being disturbed, he himself saw in this already well-established fact one of the evidences that the whole explanation for heterogeneity could not be provided by differential freezing, which without upward flotation must locate the main segregate at or near the pipe. He, however, differed from some of his colleagues on the Ingot Committee, in that he thought that differential freezing provided a material contribution to the amount of those segregates already in emulsified form in the fluid steel, the

presence of these latter having been demonstrated experimentally by Professor Andrew and his colleagues.

He failed to understand the attitude of the proponents of differential freezing, who had never to his knowledge justified their belief by reconstructing, purely on that theory, the  $\Lambda$  form of segregate as found in killed ingots. That formation was the inevitable result if rising of the segregates in the fluid steel was admitted. The accentuated segregation in large ingots as compared with small followed as a natural consequence.

When a special test had been made by casting an ingot in a sloping mould (example No. 46 of the Fourth Report of the Committee on the Heterogeneity of Steel Ingots<sup>1</sup>), there resulted an out-of-balance of the  $\Lambda$  segregate which could be explained by rising of the segregate but not by differential freezing.

Again, the Parsons-Duncan ingot-casting method,<sup>2</sup> designed to provide for clearance from segregates by giving them the best facilities for their upward flotation, proved largely successful in that respect. That ingot had indeed provided some evidence of the operation of differential freezing, but only as regarded a local and structural feature.<sup>3</sup>

These various facts, and the work of Professor Andrew and his colleagues, surely could not be ignored or readily explained away.

It had been mentioned in the verbal discussion that the segregation found in non-ferrous ingots could be explained by differential freezing, but was such segregation anything like the kind found in steel ingots? Although he had no special knowledge of non-ferrous ingots, he rather doubted it.

Referring to the more specific subject of the paper, he thought that in Figs. 1 and 2 the author scarcely did justice to the standards achieved in the casting of ingots from killed steel. Fig. 2 (a) was, in fact, representative of the type of ingot which under the best practice had for many years been regularly produced, and without the aid of anti-piping compounds.

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### AUTHOR'S REPLY.

The AUTHOR, in reply, wished to express his thanks to all those who had taken part in the discussion, both verbal and written, and, in particular, to Mr. Whiteley for his contribution. Mr. Whiteley, however, appeared to be under the impression that he (Dr. Gregory) had halted between the two opinions, *viz.*, the differential freezing hypothesis and the two-phase liquid theory, in regard to the cause

<sup>1</sup> *Iron and Steel Institute*, 1932, *Special Report*, No. 2.

<sup>2</sup> Sir Charles Parsons and H. M. Duncan, *Journal of the Iron and Steel Institute*, 1929, No. I., p. 255.

<sup>3</sup> L. Northcott, *Journal of the Iron and Steel Institute*, 1934, No. I., p. 171.

of segregation which occurred in steel ingots. He was afraid that Mr. Whiteley had misinterpreted his remarks on pp. 267 and 271 of the paper, where he had stated that "*a basic cause of major segregation may be the formation of a partially miscible liquid complex*" and that he had "no hesitation in stating that differential freezing is a fundamental cause of segregation in steel ingots." It would seem that Mr. Whiteley had not clearly understood the implication of these two statements. In his summary, the author had expressed the view that "*major segregation in steel is a consequence of the initial separation of the homogeneous liquid metal into two liquid phases, followed by an enrichment of one or even both of the liquid conjugates as solidification progresses.*" Surely this statement explained itself. The implication was that emulsification was the *primary* cause of major segregation, but a contributory *secondary* factor was differential freezing, which must occur when either of the liquid conjugates froze under ordinary casting conditions. *Minor* segregation, a consequence of the entrapment of impure liquid between the arms of freezing dendrites, was, in his opinion, essentially due to differential freezing. The slower the rate of cooling, the less marked should be the influences of differential freezing, both in regard to major and to minor segregation, and if the ingot of molten steel was cooled under ideal "equilibrium" conditions, the effects of differential freezing should, theoretically, be non-existent.

Mr. Whiteley complained that the (a) blooms of Figs. 8 and 10 showed no segregate. He (Dr. Gregory) could not agree since the average analyses of blooms (a) showed that they were considerably richer in carbon, manganese, sulphur and phosphorus than those parts of blooms (b) and (c) at positions below the major segregates.

Mr. Whiteley had stated that there was an unmistakable tendency for the major segregate to appear near the pipe cavity, but this only occurred when freezing of the metal in the head was delayed by a combination of the application of the anti-piping compounds and after-teeming. The author agreed that more decisive evidence might have been obtained by sectioning ingots instead of blooms, but Mr. Whiteley would undoubtedly appreciate the fact that in such an extensive series of experiments the question of cost had to be considered. More than 100 tons of steel would have had to be scrapped in this investigation had ingots been sectioned instead of blooms.

Mr. Whiteley was under a mistaken impression that the *whole* of the work had been done on incompletely killed steels. This was definitely not the case and the author would draw Mr. Whiteley's attention to the analyses given in the paper and to the fact that the liquid surface during freezing sank to the extent of between 8 and 10 in. Further, in practically all instances, aluminium was added to the mould during teeming.

Mr. Whiteley's observations in regard to the manganese/sulphur ratios were interesting and he (Dr. Gregory) was in agreement with



his deduction that the partial recovery of the ratio of the manganese to the sulphur increment in after-teemed ingots was essentially a consequence of the addition of fresh metal. Further, this recovery would not be expected in the asbestos-treated ingots, where it had been shown experimentally that the freezing of the metal in the feeder-head was delayed to a much lesser extent than when anti-piping compounds were used.

The analyses of the drillings obtained at the positions were carried out by senior skilled chemists of long experience, so that Mr. Whiteley need have no qualms regarding the accuracy of the recorded results, particularly in regard to the manganese determinations. The latter were determined by the bismuthate process, and Mr. Whiteley would probably be aware that this was generally recognised as one of the most accurate methods for the determination of this element. Mr. Whiteley was apparently obsessed with the idea that manganese and sulphur segregation should exist side by side, but surely this view was opposed to his (Mr. Whiteley's) own theory that sulphur in molten steel existed essentially as iron sulphide and that manganese sulphide was only formed after solidification.

Dr. Hatfield, perhaps the most vigorous exponent of the differential freezing theory, complained that the author had not brought forward a shred of new evidence from practical experiment. Was this quite true? In actual fact, in no ingot previously examined by the Committee had there been indicated such an astounding degree of segregation as was indicated in the present paper. In his (Dr. Gregory's) opinion the reason for this was the fact that it had always been *assumed* that the greatest degree of segregation would be found in the vicinity of the base of the primary pipe cavity, but he had shown that, without delayed freezing in the head, the highest concentration of impurities occurred at a point considerably below the base of the pipe. Dr. Hatfield had stated in the discussion that the drillings taken at the "standard" positions from the ingots examined by the Committee had no relation to segregation.

Dr. Hatfield apparently objected to the phenol-water system being advanced in support of the conjugate-liquid theory. This analogy was selected simply because in this case it was possible to observe clearly the changes which occurred during cooling of the initially homogeneous liquid. Dr. Hatfield complained of lack of evidence in support of the two-liquid theory, and the author would like to ask what kind of evidence Dr. Hatfield required. The enormous difficulties in regard to establishing definitely the real cause of major segregation would, he felt sure, be appreciated. At the very least, the system was quaternary, and any geometrical representation of such a system was almost outside the limitation of human thought. He (the author) could claim to have some considerable knowledge of ternary systems, but when it went beyond that to quaternary, quaternary and systems of a still higher order he was content to leave the physical conception to the mathematicians.



With regard to other evidence in support of the conjugate liquid theory of segregation, the author would like to refer Dr. Hatfield to Figs. 4 and 5 of the contribution of Professor Andrew and his co-workers to the Eighth Report of the Ingot Committee,<sup>1</sup> where there was evidence of a two-layer system prior to solidification. It might be asked what evidence Dr. Hatfield could give to support the theory that differential freezing was solely responsible for major segregation. He had drawn attention to ingots rolled immediately after casting by Mr. Talbot many years ago in which liquid came out of the end of the ingot, this liquid being the segregate. As Mr. Whiteley had pointed out, however, this was no evidence at all that the segregate was due entirely to differential freezing and not to de-emulsification, since that was just what one would expect in the light of the conjugate liquid theory.

Dr. Hatfield also indicated that owing to the use of a drill of  $\frac{1}{4}$  in. in dia., the author's results were very empirical and did not give a proper conception of the variations in composition throughout the ingot. The author agreed, but ventured to suggest that the degree of segregation would have been still more marked had a much smaller drill been employed, and, in his opinion, it would then have been still more difficult to explain this extraordinary degree of segregation on the basis of the differential freezing hypothesis alone.

Apparently, what Dr. Hatfield (and also Dr. Desch) did not appreciate was the fact that, according to the principles of differential freezing, the ingot should be more homogeneous, *i.e.*, the degree of segregation should be less pronounced the more slowly it was cooled during solidification, as, for instance, when delayed freezing was resorted to. In actual fact, exactly the opposite had taken place, as was obvious from an examination of the analyses at the A positions indicated in Fig. 3.

Dr. Binnie had stated that in the ingots examined by the Ingot Committee, the sulphur segregate was always right up against the pipe cavity. The author did not agree and would refer Dr. Binnie to the reply to Dr. Hatfield's remarks. He was at a loss to understand Dr. Binnie's comment in regard to the "moving about" of the segregate. Did Dr. Binnie really mean that the segregate could move about in a *solid* ingot or bloom? Any flow of the segregated zone must necessarily be determined by the flow of the solid mass as a whole.

Dr. Binnie claimed that the high-sulphur free-cutting steels when analysed were very uniform in composition, and that the sulphur at the top agreed "very closely" with that at the bottom. It would have been interesting had Dr. Binnie given some indication of this very close agreement, but he (Dr. Gregory) had no doubt that Dr. Binnie would be cognisant of the fact that uniformity in the composition of an ingot of free-cutting steel was best obtained by

<sup>1</sup> Eighth Report on the Heterogeneity of Steel Ingots, Plates II. and III., *Iron and Steel Institute*, 1939, *Special Report No. 25*.

casting at a correct temperature in ingot moulds of relatively small cross-section. The larger the ingot the greater was the variation in composition between top and bottom, a fact which could not be explained satisfactorily on the basis of differential freezing, since then the rate of freezing was considerably slower than in ingots of smaller cross-section. Dr. Binnie had asked whether 0.029% of sulphur was a supersaturated solution of sulphur in steel, but the author would like to point out that the question of supersaturation had not even been mentioned in the paper. Further, Dr. Binnie was apparently ignoring the presence of the other impurities in the steel in connection with segregation. His statement regarding the *absolute* homogeneity of the cast of steel which had been held up for over an hour in the ladle was most interesting, but it would have been still more interesting had Dr. Binnie given some indication of the tapping temperature which, to say the least, must have been extraordinarily high in order to get the steel out of the ladle. In any case, however, the author could not accept, without further details, this experience as evidence against the conjugate liquid theory.

Dr. Desch's remarks were of considerable interest, but to him (Dr. Gregory) somewhat conflicting. In the first place, Dr. Desch thought that the author had not been quite fair in stating that Professor Andrew's view was that a completely immiscible phase was formed within the melt. In this regard he could only refer Dr. Desch to the last paragraph on p. 3 of the Eighth Report of the Committee, although he (Dr. Gregory) had every reason to think that Professor Andrew was now prepared to accept the hypothesis that major segregation was a consequence of the separation of the liquid steel into two conjugates rather than of the formation of a completely immiscible liquid phase.

Dr. Desch admitted that an "immiscible complex" containing sulphur, oxygen, iron and manganese did form, but that he had never seen any evidence to convince him that this complex contained appreciable quantities of either carbon or phosphorus. The author ventured to suggest that the evidence was given in the paper and if Dr. Desch would only consider the results of the analyses at positions A of Figs. 3 and 4, he must come to the conclusion that the segregation of the above elements was definitely accompanied by the segregation of both carbon and phosphorus. How, then, did Dr. Desch propose to explain this segregation? Was it to be assumed that the segregation of sulphur, oxygen, iron and manganese was due to the formation of an immiscible complex and that the segregation of carbon and phosphorus was due to differential freezing? With such an opinion the author was unable to agree, in view of the evidence obtainable from published work on the Fe-FeS-MnS, Fe-FeS-Fe<sub>3</sub>P and Fe-Fe<sub>3</sub>C-FeS systems. Most commercial steels also contained copper and the author had also indicated that the existence of conjugate liquid solutions had been demonstrated in the ternary iron-copper-oxygen system. Dr. Desch considered

that the relevant concentrations in these ternary solutions were far outside the concentrations met with in commercial steels. The author had pointed out, however, that almost any commercial steel was at least quinary and it was surely unwise to assume that similar concentrations were needed to yield conjugate liquid solutions as in the simpler ternary systems.

Dr. Desch was of the opinion that the liquid towards the end of the freezing "had been very much pushed about, partly by the anti-piping compound, partly by the movement of gases and partly by the forging of the ingot down to a bloom." What evidence had Dr. Desch to support these contentions? In the first place, it was difficult to understand how this "pushing about" of the liquid last to freeze was accomplished by the addition of a light powder to the surface of the liquid steel in the mould immediately after teeming. The application of the powder could not possibly result in any real disturbance of the metal surface, let alone a pushing about of the layers below that surface. Secondly, the author would ask Dr. Desch what gases were likely to be liberated during freezing which would influence the position of the major segregate? All the steels examined contained appreciable amounts of silicon and manganese, and most of them were aluminium killed. In regard to Dr. Desch's contention that the liquid had been pushed about by the forging of the ingot down to a bloom, the author could not see how this was likely to influence the subject under discussion. All that the cogging did was to lengthen the segregated zone but, nevertheless, the segregate would occupy the same relative position in the bloom as in the ingot.

Turning now to Dr. Northcott's remarks, the author failed to see what evidence he had put forward in favour of the differential solidification theory and against the phenol theory. Dr. Northcott apparently based his remarks on the results of his own experiments on copper alloys. It was, indeed, unfortunate that he had not examined the copper-iron system or, rather, the copper-iron-oxygen-carbon system. Had Dr. Northcott done so he would, no doubt, have obtained evidence which could only be explained on the basis of the conjugate liquid theory. He (Dr. Gregory) would point out that in any commercial steel there were present a number of elements which, in binary and ternary systems at least, gave rise to the formation of liquid conjugates, but this was not to say, as might be implied from Dr. Northcott's remarks, that all metallic systems separated into two liquids before freezing. That was certainly not the case and this misinterpretation by Dr. Northcott was unfortunate.

Dr. Northcott stated that he had obtained a degree of segregation with non-ferrous alloys of a similar order to those described in the present paper. If emulsification was not indicated, either from visual examination or the examination of the relevant equilibrium diagrams, then he (Dr. Northcott) was quite justified in ascribing this segregation to differential freezing, but only if the degree of



segregation was less pronounced with slow cooling through the freezing range. In the author's experiments, delayed freezing resulted in a greater concentration of impurities, an effect diametrically opposed to the principles of differential freezing.

Dr. Swinden's remarks were particularly welcome since he had drawn attention to the practical aspect of the use of anti-piping compounds. He (Dr. Gregory) agreed that the primary function of these compounds was heat-insulation. In this respect, fineness of division undoubtedly played a very important part and, perhaps unfortunately, this necessarily meant a shorter oxidation period during which heat was being generated. Heat-generation was undoubtedly important but secondary to heat-insulation, and, as Dr. Swinden had stated, care and common sense must be used when applying these compounds, otherwise real practical difficulties might arise.

Dr. Swinden questioned the author's statement "that on the basis of differential freezing, the last material to freeze or solidify should be richest in impurities, so that these should be concentrated in the vicinity of the primary pipe," but surely this followed from the very principle of differential freezing. If the purer layer on top solidified first then, in view of the fact that molten steel contracted on freezing, the final contraction cavity should be formed in the impure zone. Dr. Main had also referred to this point and given a rational explanation as to why, in most of the ingots examined, the position of the main segregate was not coincident with the base of the pipe. Dr. Main's remarks regarding the formation of the  $\Lambda$  segregates were of much interest and gave an answer to those critics who still adhered to differential freezing as the sole cause of major segregation.

Dr. Main stated that Fig. 2 (a) represented a standard which under good practice had been produced for a long time without using anti-piping compounds. So far as the high-class alloy steels were concerned this was perfectly true, but Dr. Main would no doubt agree that with such steels it was the usual practice to employ deeper feeder-heads which were preheated before the molten metal was poured into the ingot moulds. The author's remarks in regard to the shape of the pipe referred particularly to medium and mild carbon steel ingots, however, where more squat heads were employed, for obvious reasons, and where preheating was absolutely out of the question.

The author was indebted to Mr. Harris for his confirmatory remarks concerning the raising of the major segregate when anti-piping compounds were used. In regard to the use of these compounds on ingots without feeder-heads he had to confess that he had no experience whatever. There was no reason to suppose, however, that under such circumstances similar, if not quite the same, advantages should not be obtained as when applied to feeder-head ingots. Mr. Harris' contention that with feeder-heads plus

after-teeming it had been found possible to use a smaller amount of "head" was, of course, a point of great practical importance and economy.

Regarding the purity of the zones *G* and *F*, the author was of the opinion that this was due essentially to differential freezing, since, even with delayed freezing, solidification must obviously commence at the outside. The relatively low carbon contents of these zones was sufficient evidence that the amount of carbon pick-up from the anti-piping compound was negligible.

Dr. O'Neill's comments were both welcome and interesting, but he (Dr. Gregory) could only assume that the exothermic reactions associated with the use of compounds *X* and *Y* occurred too rapidly and perhaps almost spontaneously. To be really efficient, the exothermic oxidation of any oxidisable element in the compound should occur at a relatively slow rate. The compounds employed by Dr. O'Neill were relatively low in carbon, whereas the most satisfactory mixtures, judged by the author's experimental results, contained upwards to 50% of carbon. In compound No. 5 the carbon existed essentially as graphite, a form of carbon which was notoriously slow in regard to oxidation and, moreover, was not readily absorbed by molten iron and steel. It was on this account, of course, that graphite electrodes were more suitable in electric-arc furnaces than the ordinary, so-called amorphous, electrodes; it was well-known that the amount of carbon pick-up and electrode consumption per ton of steel were considerably lower when graphite electrodes were employed.

Dr. O'Neill would also observe that the silica/alumina ratios of compounds *X* and *Y* differed considerably from those of compound No. 5 and these might have had a great importance on their heat-insulating properties. As Dr. Swinden had pointed out, the fineness of division of the particles of the compound was also a matter of considerable importance.

Summarising, it was evident from the discussion that the members of the Ingot Committee were sharply divided, some supporting the author's views and others holding that differential freezing was solely and absolutely responsible for the major segregation which occurred in steel ingots. The latter view, so it seemed to the author, was based essentially on the conventional iron-carbon equilibrium diagram. The author had witnessed the casting of many thousands of tons of molten steel and, from actual visual observation, was convinced that liquid steel, immediately before freezing, was definitely not homogeneous and he could only assume that the opponents of the two-liquid hypothesis had not seen molten steel often enough or, alternatively, had not sufficiently closely observed the physical changes which occurred during and immediately after teeming.





# HEAT TRANSFER IN THE FLOW OF GAS THROUGH A BED OF SOLID PARTICLES.\*

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(Figs. 11 to 16 = Plates XVI. to XXI.)

## SUMMARY.

The problem of the transfer of heat from a gas to a bed of solid particles is approached from first principles, in order to relate the heat transfer to the shape and dimensions of the bed and particles, the physical characteristics of the material, the velocity and temperature of the gas, &c.

It is shown theoretically that the heat transfer is governed by the dimensionless groups  $V\tau c'/lc$  and  $Vlc'/k$ , and by the shape of the bed and particles ( $V$  = mean linear velocity of the gas entering the bed;  $\tau$  = time;  $c'$  = specific heat of unit volume of gas at constant pressure;  $l$  = characteristic linear dimension;  $c$  = specific heat of unit volume of material of the particles;  $k$  = conductivity of the particles); also that  $Vlc'/k$  may be neglected if it is small enough, that is to say, if the size,  $l$ , of the particles is small enough, or their conductivity,  $k$ , large enough, for the effects of temperature differences in their interiors to be neglected; in such cases the thermal conductivity of the particles is of no importance.

Once the validity of these groups has been checked experimentally, the results can be applied to the whole possible range of materials, provided that their physical constants are known.

Experiments to test out the theory are described, in which hot air was passed through beds of various depths of steel, lead or glass spheres of diameter up to 0.25 in. It was found that the results for different sizes, velocities and materials could be correlated with  $V\tau c'/lc$ , indicating that the effects of temperature differences within the particles were negligible in the experiments.

Curves are given for calculating the variation of gas temperature through a given bed at any given moment. It is shown, for example, that the time taken to attain a given temperature at a given depth of bed is directly proportional to the specific heat and density of the particles, inversely proportional to the gas velocity, and only slightly affected by changes of particle size. Curves are also given for the heat transfer.

The highest value of  $Vlc'/k$  in the experiments was about 4, corresponding to diameters of 0.25 in. and 11 in. for glass and steel, respectively, at an air speed of 2 ft. per sec. The results are, therefore, applicable up to these sizes; how far they are valid for larger sizes remains to be found by further experiments, but rough calculations show that the errors in using them up to sizes two or three times those quoted are probably only a few percent.

Although only part of the ground has been covered in the present experiments, it is hoped that the methods developed will in due course be extended to cover the whole field, and eventually include the more complicated conditions found in industrial plant.

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\* Received March 5, 1940.

## INTRODUCTION.

In designing industrial plant for the transfer of heat from a gas to a bed of solid particles, the lack of fundamental information has been a great handicap. The general problem is to relate the heat transfer to the shape and dimensions of the bed and particles, the physical characteristics of the material of the particles, the velocity and temperature of the gas, &c.

The present investigation approaches the problem from first principles, endeavouring to correlate the effects of the different variables. Theoretical considerations show that the heat transfer is governed by certain dimensionless groups of variables, just as the nature of fluid motion is governed by the well-known group of variables

$$\frac{\text{Velocity} \times \text{Linear size}}{\text{Kinematic viscosity}},$$

known as the Reynolds number. But since certain assumptions and approximations have to be made in the theory, experiments with beds of spheres were made to test out the dimensionless groups arrived at.

The heat has to be transferred in two stages : first by convection from the gas to the surface of the particles, and secondly by conduction to the interior of the particles. As would be expected, the theory shows that for particles of small size or large conductivity, the heat transfer should be practically independent of conductivity ; but the limits within which this is true can best be found experimentally. So far, however, the point at which conductivity becomes important has not been reached. The present experiments, therefore, cover only part of the ground and the results are of limited application, but it is hoped that the methods developed will in due course be extended to cover the whole field, and eventually include the more complicated conditions found in industrial plant.

## PREVIOUS WORK.

The only previous investigations of the fundamentals of the problems were attempted by T. E. W. Schumann<sup>(1)</sup> and by C. C. Furnas.<sup>(2)</sup> Schumann investigated mathematically the simple case of an incompressible fluid passing uniformly through a bed of perfectly conducting solid particles. He calculated the time variation of the fluid and solid temperatures at any distance through the bed in terms of the initial temperature of the bed, the constant inlet temperature of the fluid, the coefficient of heat transfer from fluid to particles per unit volume of bed, and the size, specific heat, &c., of the particles.

Furnas carried out two series of experiments. In the first series he passed heated air through a bed of iron balls and attempted to measure the temperatures of the air and balls by suction thermo-

couples, but so many difficulties were encountered that this method was abandoned.

In the second series hot combustion gases were passed upwards through cylinders filled in turn with iron ores, coke, coal, anthracite, limestone, iron balls, crushed brick, slag and a typical blast-furnace charge. The sizes of the particles ranged from 0.4 to 7.3 cm., and two sizes of container were tried, one 15 cm. wide by 50 cm. high, and the other 23 cm. wide by 100 cm. high. The gases were led into the initially cool bed at various constant temperatures up to 1000° C. through a central hole of diameter 5 cm. in the bottom of the container. The temperature of the gases leaving the bed was recorded throughout the experiment, and the temperature-time curve thus obtained was compared with Schumann's theoretical curves for different assumed heat-transfer coefficients. By finding the theoretical curve which most nearly resembled in shape the experimental one, a value of the heat-transfer coefficient was deduced. Furnas gave a formula for the heat-transfer coefficient in terms of the gas velocity, particle diameter, voidage fraction and a constant,  $A$ , "characteristic of the substance of the particles." His values for  $A$  ranged from 0.0042 for bituminous coal to 0.015 for Cuyuna ore, but he was unable to relate this variation to any physical properties of the substances. He "could not arrive at any definite conclusions about the effects of change in the size or nature of the particles," and concluded that "it remains necessary to determine  $A$  for each substance used."

A criticism of Furnas' experiments is that the heat capacity of his insulated container was several times that of the particles inside; his results may, therefore, not be free from its effect, which would be different for different beds and might make comparison between them unreliable. Also, owing to the small size of the hole through which the gases entered some of the beds, the flow was far from uniformly distributed across the bed. Again, there were not enough particles to the container diameter for the effect of the walls upon the packing to be disregarded, which may mean that Furnas' conclusion that the heat transfer is proportional to  $d^{-0.9}$ , where  $d$  is the particle diameter, is peculiar to the sizes of particle and container used by him. Furnas was surprised at the low index, 0.9, and suggested that for smaller sizes "an increasing proportion of the open spaces in the bed becomes too small to permit the passage of a significant amount of gas, so that the relative area in contact with the gas stream in the smaller sizes becomes less." This explanation neglects the increase in velocity which must result from partial blocking of the bed if the total flow remains the same; although Furnas himself later says, when explaining the increase in the heat transfer with decrease in the voidage fraction, that "decreasing the voids also increases the linear velocity."

It is doubtful whether Furnas' results are applicable except in the particular circumstances of his experiments.

## APPLICATION OF THE THEORY OF DIMENSIONS.\*

*General.*

A detailed account of the application of the theory of dimensions to the transfer of heat in the flow of gas through a bed of solid particles is given in Appendix I., where it is shown, on certain assumptions, that the heating up of the bed depends only upon its shape and upon the two dimensionless groups :

$$\frac{V\tau c'}{lc} \text{ and } \frac{Vlc'}{k}$$

where  $V$  = velocity of gas,  
 $l$  = characteristic linear dimension of bed,  
 $c$  = specific heat per unit volume of material of particles,  
 $k$  = conductivity of particles,  
 $c'$  = specific heat per unit volume of gas, and  
 $\tau$  = time.

Of these, the group  $Vlc'/k$  can be neglected when small enough, i.e., if the particles are small enough, or have a high enough conductivity, for differences of temperature in their interiors to be neglected.

*Beds of Spheres in Cylindrical Containers.*

In the particular case of a bed of spheres, each of diameter  $d$ , in a cylindrical container of diameter  $D$  and height  $h$ , with the gas flowing parallel to the axis, the shape of the bed is determined only by  $D/d$  and  $h/d$ . For beds wide compared with the diameter of the spheres,  $D/d$  need not be considered, and the shape is determined only by  $h/d$ .

If  $t_0$  is the initial temperature of the bed,  $t_g$  the constant inlet temperature of the gas entering it, and  $t_g'$  the variable outlet temperature of the gas leaving it, it follows that, putting  $d$  for  $l$  :

$$\frac{t_g' - t_0}{t_g - t_0} \text{ depends only upon the three groups } \frac{V\tau c'}{dc}, \frac{Vdc'}{k} \text{ and } \frac{h}{d}. \quad (1)$$

The theory also shows that the total heat transfer,  $Q$ , from the gas to the bed during time  $\tau$  is expressed in a relation between

$$\frac{4Q}{\pi D^2 hc(1-f)(t_g - t_0)}$$

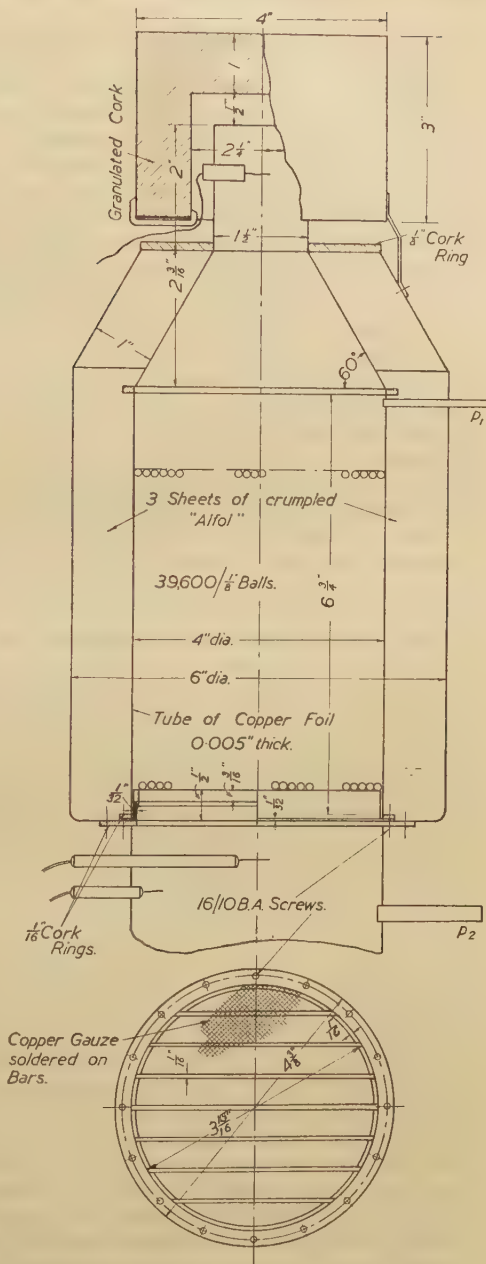
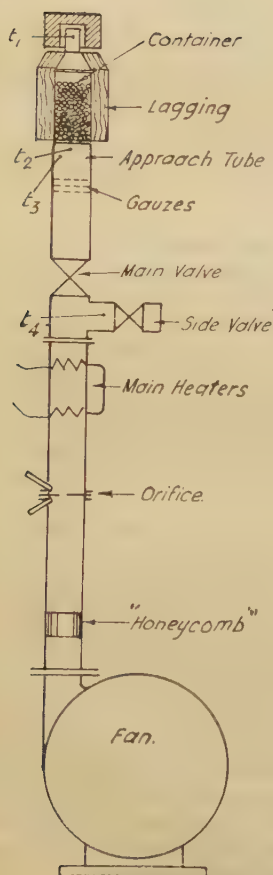
and the same three groups.

If the particles are small enough, or their conductivity is high enough, for the effects of temperature differences in their interiors to be neglected :

$$\frac{t_g' - t_0}{t_g - t_0} \text{ and } \frac{4Q}{\pi D^2 hc(1-f)(t_g - t_0)} \text{ depend only upon } \frac{V\tau c'}{dc} \text{ and } \frac{h}{d}. \quad (2)$$

\* A list of the symbols used will be found at the end of the paper.





## GENERAL DESCRIPTIONS OF APPARATUS AND EXPERIMENTS.

Figs. 1 and 11 show the general arrangement of the apparatus. The container was filled to any desired depth with spheres of either steel, lead or glass. A flow of heated air upwards through the bed was then started as nearly instantaneously as possible, the inlet air temperature,  $t_2$ , being kept constant and the outlet air temperature,  $t_1$ , recorded at intervals until it reached the constant inlet temperature. Cool atmospheric air was then substituted as quickly as possible for the hot air, and the temperature  $t_1$  was recorded as it fell back to atmospheric temperature. The experiment was repeated for different rates of air flow.

To compare the behaviour of similar beds, three similar containers of different sizes were made, and were filled to various fractions of their full depths with spheres of diameters in proportion to the sizes of the containers (see Fig. 12). The remainder of the experimental apparatus was the same with all three containers, except for the convergent, straight or divergent leading-in tubes needed to connect the containers with the air delivery tube.

The uniformity of the distributions of the velocity and temperature over cross-sections of the bed is indicated in Appendix II.

*Details of Apparatus and Measurements.*

Fig. 2 and Table I. give details of the three containers, 2, 4 and 8 in. in dia., respectively, shown side by side in Fig. 12. The containers were of thin copper sheet, the grates supporting the balls being of steel, as light as possible, covered with gauze. Cork insulating rings between the container and grate, and between the grate and the leading-in tube, reduced the heat flow from the leading-in tube to the container. Table I. gives the heat capacity of the containers and their insulation. This amounted to only a few percent. of the heat capacity of the balls, and a correction was made for it. The capacity of the grate was neglected, since it very quickly reached the inlet-air temperature.

The containers and leading-out tubes were insulated with "Alfol," 2 in. thick on the 8-in. container, and 1 in. thick on the 4-in. and 2-in. containers. The proportionately thicker insulation on the 2-in. container was found necessary to prevent the balls from cooling too much during the change-over from hot to cool air, but it was found to have little effect on the main results (Appendix III.).

Air from a centrifugal fan at pressures up to 13 in. of water, was passed in turn through a honeycomb, a measuring orifice (Appendix IV.), electric wire heaters and a control valve, from which it was led into the container. A valve in a side tube enabled the air from the fan to be passed directly to atmosphere when desired. In the 2-in. and 4-in. apparatus the control valves were adjustable clamps fitted to rubber tubes forming part of the main and side tubes, but in the 8-in. apparatus sliding dampers were used.

TABLE I.—*Details of the Containers.*

	Diameter of Container, In.		
	8.	4.	2.
Diameter of steel balls. In. . . .	0.25	0.125	0.0625
„ „ lead balls. In. . . .	0.233	...	...
„ „ glass balls. In. . . .	0.237	...	...
Mass of bed of steel balls, $h/d = 41$ . G. .	41,050	5,113	660
„ „ lead balls, $h/d = 36$ . G. .	59,900	...	...
„ „ glass balls, $h/d = 37$ . G. .	14,950	...	...
Heat capacity of bed of steel balls, $h/d = 41$ . Cal. per °C. . . .	4,560	568	73.3
„ „ lead balls, $h/d = 36$ . Cal. per °C. . . .	2,080	...	...
„ „ glass balls, $h/d = 37$ . Cal. per °C. . . .	2,520	...	...
Heat capacity of container. Cal. per °C. .	39.2	13.0	1.7
„ „ supporting grate. Cal. per °C. . . .	84.2	12.0	1.9
Heat capacity of container and supporting grate as a percentage of that of the steel balls . . . .	2.6	4.4	5.2
Heat capacity of container and supporting grate as a percentage of that of the lead balls . . . .	6.0	...	...
Heat capacity of container and supporting grate as a percentage of that of the glass balls . . . .	4.8	...	...
Thickness of "Alfol" lagging. In. . . .	2	1	1
Number of crumpled "Alfol" sheets . .	5	3	4

The steel balls were ordinary ball bearings of diameter 0.25, 0.125 and 0.0625 in. The lead balls were shot of mean diameter 0.233 in., with  $\pm 5\%$  variation in different directions, and were used only in the 8-in. container. The glass balls were nearly spherical and of mean diameter 0.237 in., and they also were used only in the 8-in. container. The balls were put in position in the beds by allowing them to fall gently from a small height, the voidage fractions being between 0.375 and 0.38, and the total number of balls in a bed between 6,000 and 40,000.

The walls of the leading-in tubes were kept as nearly as possible at the temperatures of the air passing through them by an electric heater wound round the outside, which was adjusted to keep the thermocouples  $t_2$  and  $t_3$  the same.

The air, after leaving the container, passed back down the annular space round the narrow part of the leading-out tube, thus keeping the walls close to the air temperature, which was read by the thermocouple  $t_1$ .

The static air pressure was measured by an inclined gauge connected to small holes in the wall of the container immediately above and below the bed.

*Experimental Procedure.*

With no current through the heaters, the fan was adjusted to any desired rate of flow, and when the temperature  $t_1$  had become steady, its value was taken for  $t_0$ , the initial temperature of the bed.

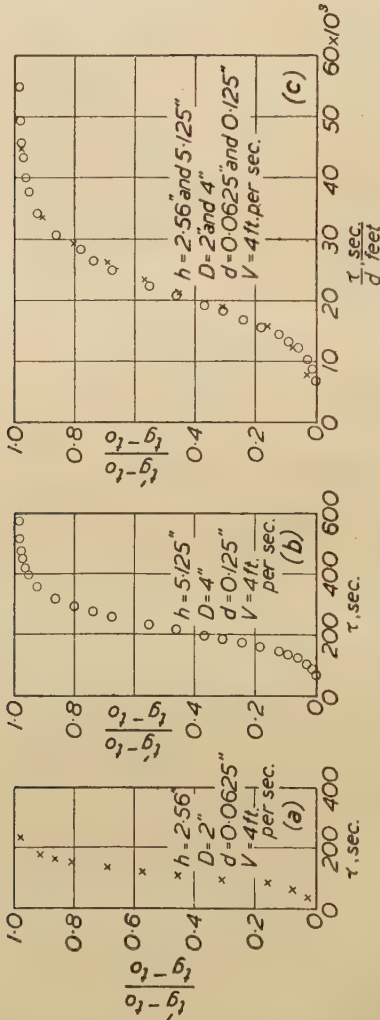


FIG. 3 (see Fig. 4).—Correlation of Results for Geometrically Similar Beds in 2-in. and 4-in. Containers, at a velocity of 4 ft. per sec.

The side valve was then opened, the main valve closed and the side valve adjusted until the rate of flow was the same as before. The heaters were then turned on and regulated to give the desired inlet

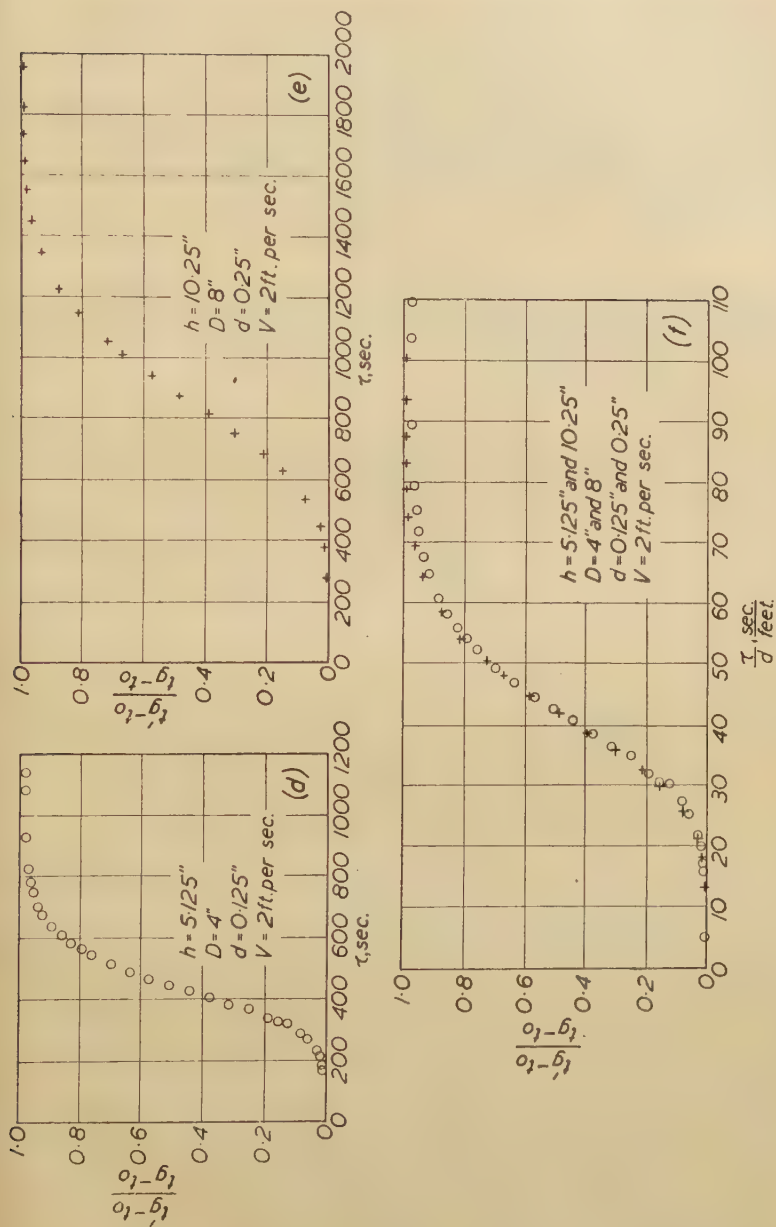


Fig. 4 (see Fig. 3).—Correlation of Results for Geometrically Similar Beds in 4-in. and 8-in. Containers, at a velocity of 2 ft. per sec.



air temperature as indicated by the thermocouple  $t_4$ . The valves were then reversed, and the experiment thus begun. Slight adjustments of the fan and heaters were necessary from time to time to keep the rate of flow and the air temperature  $t_2$  constant.

Less consistent results were obtained with the 2-in. container than with the larger sizes, the experiments with the former lasting only 2 or 3 min., rather too short a time for taking a series of temperatures without automatic recording apparatus.

### RESULTS.

In what follows,  $V$  denotes the mean air velocity at the inlet to the bed, *i.e.*, the volume flowing per unit time, reckoned at  $17^\circ \text{C}$ ., divided by the cross section of the empty container.

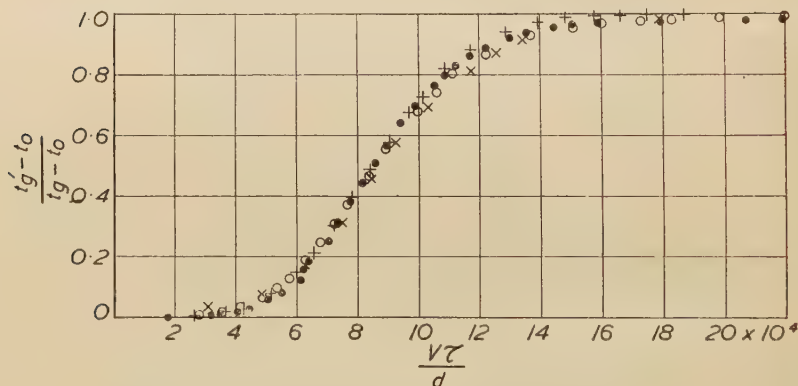


FIG. 5.—Correlation of Results at Different Velocities.

#### *Comparisons between Geometrically Similar Beds of Different Sizes.*

Fig. 3 shows results for the heating of steel balls with  $V = 4$  ft. per sec.; curve (a) is for  $D = 2$  in.,  $h = 2.56$  in.,  $d = 0.125$  in., and curve (b) is for  $D = 4$  in.,  $h = 5.12$  in.,  $d = 0.25$  in.

The two beds were thus geometrically similar, the second being twice the size of the first, and curve (c) shows how the results for both beds fall on the same curve when  $(t'_g - t_0)/(t_g - t_0)$  is plotted against  $\tau/d$ .

Fig. 4 shows another example of two similar beds, of diameters 4 in. and 8 in., the velocity being 2 ft. per sec. in each case; the curve (f) shows how the results may be correlated.

These results are typical comparisons of similar beds. In Fig. 5 all the above results have been plotted against  $V\tau/d$ , and it is seen that the points for both velocities fall closely on one curve.

### *Correlation of All Results for Steel Balls.*

Figs. 13 and 14 show the complete results for steel balls, Fig. 13 being for heating and Fig. 14 for cooling. The points are seen to be arranged about a series of curves, each for a different value of  $h/d$ , and except for some of the 2-in.-container points falling below the corresponding points for the larger sizes, the agreement between the correlated results for the different sizes and velocities is remarkably good. As already explained, on account of the rapidity of the heating, the results for the 2-in. container were less accurate than the others.

In most experiments  $D/d$  was 32. A few points for  $D/d = 16$ , denoted by open triangles in Fig. 14, fall on the same curve as those for  $D/d = 32$  and the same  $h/d$ . This shows that the containers were of large enough diameter for the effects of the walls to be disregarded, and for the results to be taken as applicable to infinitely wide beds.

In most of the experiments  $(t_g - t_0)$  was about  $84^\circ \text{C.}$ , but in a few cases smaller values were tried and the results are included in Figs. 13 and 14. They agree well with the main results; hence, other quantities being equal,  $(t_g' - t_0)$  is directly proportional to  $(t_g - t_0)$ , within the range covered.

The corresponding curves in Figs. 13 and 14 for heating and cooling, respectively, are practically identical.

### *Correlation of Results for Glass and Lead Balls.*

Figs. 15 and 16 give the results for lead and glass balls, respectively, each curve including some heating and some cooling values.

### *Correlation of Results for Different Materials.*

In Fig. 6 the results for all three materials are correlated, with  $(t_g' - t_0)/(t_g - t_0)$  and  $V\tau c'/dc$  as co-ordinates. The corrections applied in drawing Fig. 6 and also Figs. 7 and 8 are mentioned in Appendix V.

It should be noted that the points in Fig. 6 denote the positions of the mean curves drawn through the corresponding sets of points in Figs. 13 to 16. The full lines in Fig. 6 are means drawn through the points shown, and represent the mean values for all three materials.

### *Alternative Method of Correlating Results.*

Fig. 7 shows the same results as Fig. 6, but with a different abscissa, suggested because the area,  $S$ , enclosed between any curve in Fig. 6 and the  $y$ -axis must always be given by :

$$S = h(1 - f)/d, \quad \dots \dots \dots (3)$$

from which it follows that the corresponding area in Fig. 7 must be

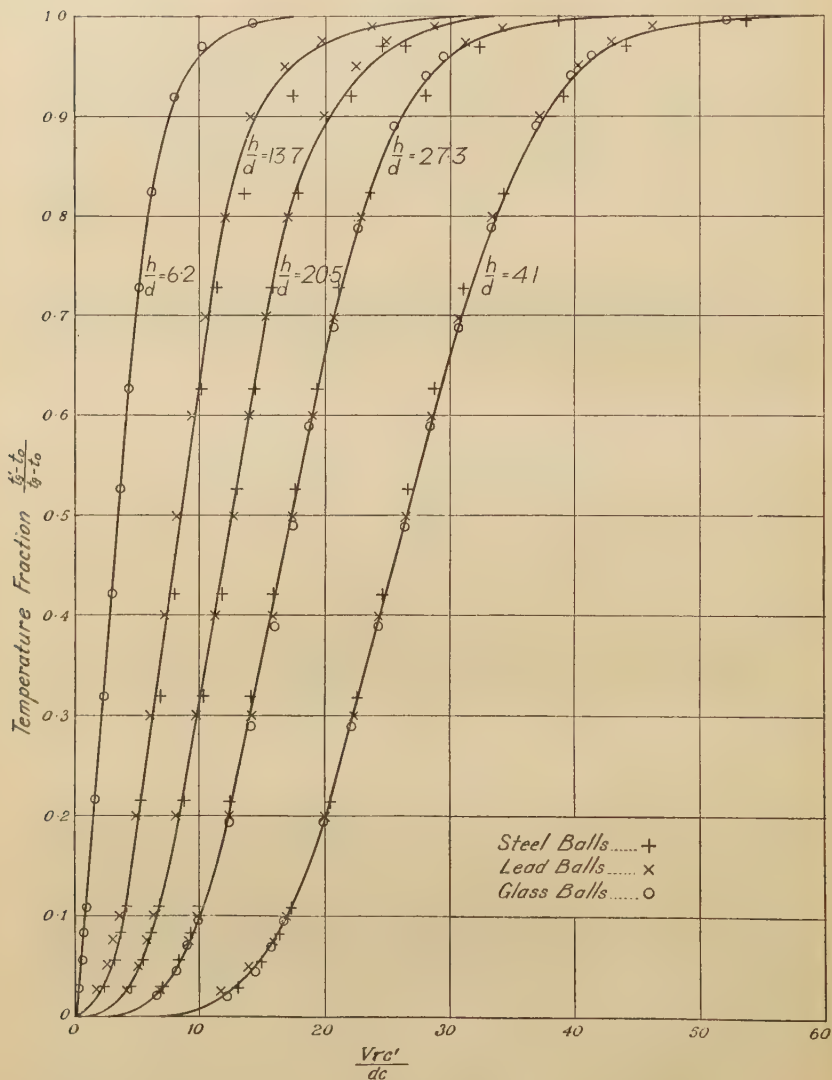


FIG. 6.—Correlation of Results for Steel, Lead and Glass. (The points are from the mean results in Figs. 13 to 16, after making the slight correction described in Appendix V.; the lines are drawn through the mean positions of the points shown.)

unity for all the curves. Measurements with a planimeter verify this. Equation (3) may be proved as follows :

The heat given up in time  $d\tau$  by gas entering the bed at  $t_g$  and leaving at  $t_g'$  is :

$$Vc'\pi D^2(t_g - t_g')d\tau/4;$$

and the total heat given up is thus found by integrating this expression from 0 to  $\infty$ , and may be written as :

$$\frac{Vc'\pi D^2(t_g - t_0)}{4} \int_0^\infty \left(1 - \frac{t_g' - t_0}{t_g - t_0}\right) d\tau.$$

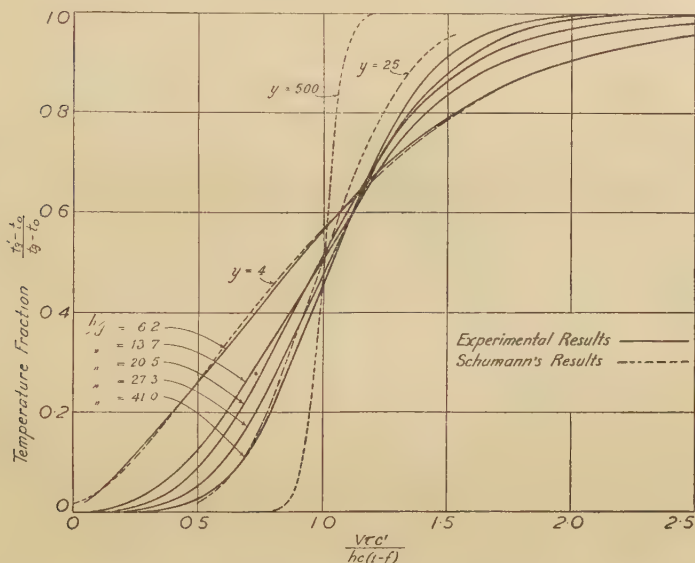


FIG. 7.—Alternative Method of Expressing Results, and comparison with Schumann's theory.

Equating this to the total heat required to warm the bed from  $t_0$  to  $t_g$ , it follows that :

$$\frac{Vc'}{dc} \int \left(1 - \frac{t_g' - t_0}{t_g - t_0}\right) d\tau = \frac{h(1-f)}{d},$$

the left-hand side of which equals  $S$ , the area between the corresponding curve and the  $y$ -axis in Fig. 6.

Note that the area enclosed between *part* of a curve and the  $y$ -axis in Fig. 6 cannot be related to the heat absorbed by the bed up to the corresponding stage of the heating up, because the relation between the particle and gas temperature is unknown except at the beginning and end of the process.

*Heat Transfer Between Gas and Particles.*

The total heat transfer,  $Q$ , from zero time to time  $\tau$  is given by :

$$Q = \frac{\pi D^2 V c'}{4} \int_0^\tau (t_g - t_g') d\tau \quad . \quad . \quad . \quad (4)$$

But the area in Fig. 7 enclosed by the part of any one curve between abscissæ 0 and  $x$  and the  $y$ -axis is  $S'$ , where :

$$S' = \int_0^x \left(1 - \frac{t_g' - t_0}{t_g - t_0}\right) d \left[ \frac{V \tau c'}{h c (1 - f)} \right] \quad . \quad . \quad . \quad (5)$$

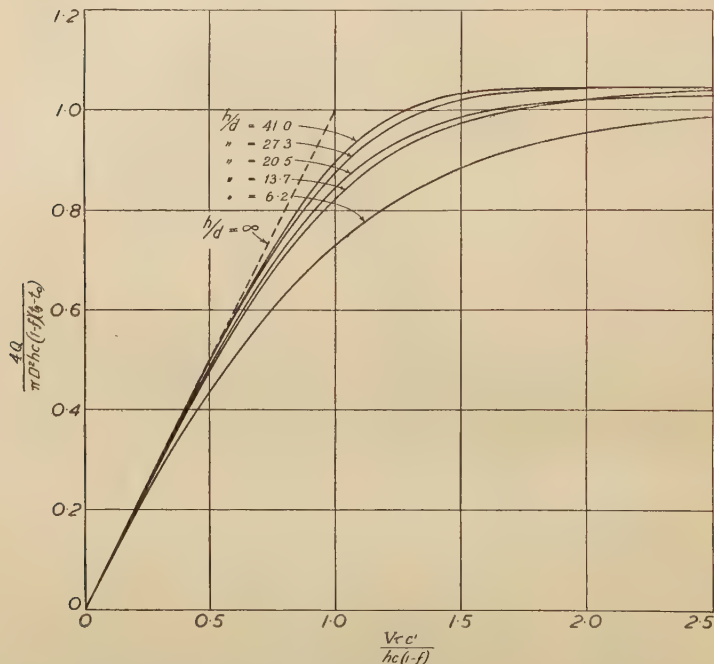


FIG. 8.—Curves for Calculating Total Heat Transfer,  $Q$ , between time 0 and time  $\tau$ .

Hence, from equations (4) and (5) :

$$Q = \pi D^2 h c (1 - f) (t_g - t_0) S' / 4,$$

where

$$x = \frac{V \tau c'}{h c (1 - f)}.$$

For a given bed, therefore,  $Q$  is proportional to  $S'$ , values for which were obtained by measurements with a planimeter on Fig. 7, and the results are shown in Fig. 8, which may be used to read off the heat transfer  $Q$  for any given conditions.



As  $\tau$  becomes very great, the heat transfer  $Q$  must approach  $\frac{1}{4}\pi D^2 hc(1-f)(t_g - t_0)$ , the total heat capacity of the bed, and the ordinate in Fig. 8 must therefore approach unity. The experimental curves approach limiting values slightly above unity, but the discrepancies are probably due to experimental error in fixing the moment at which an experiment starts, which would cause a relatively large error in the limiting ordinates of Fig. 8.

The theoretical limiting form of the curves in Fig. 8 for very large values of  $h/d$  is shown by the dotted line.

*Deduction of Heat Transfer Coefficients by Comparison of Experimental Results with Schumann's Theory.*

Schumann, by making certain simplifying assumptions, calculated curves which, in the present notation, give :

$$\frac{t_g' - t_0}{t_g - t_0} \text{ as a function of } \frac{qh}{c'V} (\equiv y) \text{ and } \frac{q}{c(1-f)} \left( \tau - \frac{hf}{V} \right) (\equiv z),$$

where  $q$  is the heat-transfer coefficient between fluid and particles per unit volume of bed.

If  $\tau$  is large compared with  $hf/V$ —that is to say, if the time from the start of the heating is large compared with the time taken by the fluid to pass once through the bed—the quotient  $z/y$  equals  $V\tau c'/hc(1-f)$ , which is the dimensionless group used in Figs. 7 and 8, and is the combination of  $y$  and  $z$  which does not contain  $q$ .

Fig. 8 gives Schumann's theoretical curves for a range of  $y$ . By selecting the theoretical curve best fitting, in shape and position, each experimental one, a value of  $y$  may be deduced for each of the values of  $h/d$  for which experiments have been done. The second column of Table II. has been obtained in this way, and the third column, which was deduced from the first and second, assuming  $c' = 0.291 \times 10^{-3}$  cal. per c.c. per  $^{\circ}\text{C}$ . for air, gives  $qd/V$ , from which  $q$  may be calculated, knowing  $V$  and  $d$ .

The heat transfer coefficient,  $\alpha$ , per unit surface of particles, may be deduced from  $q$ , in the case of a bed of uniform spheres, for the surface area of the spheres in unit volume of the bed is  $6(1-f)/d$ , whence  $\alpha = qd/6(1-f)$ , and taking the mean value of  $qd/V$  from Table II.,  $\alpha = 0.00005V$ . cal. per sq. cm. per sec. per  $^{\circ}\text{C}$ ., where  $V$  is in centimetres per second.

TABLE II.—*Experimental Heat Transfer Coefficients.*

$h/d$ .	$qh/c'V$ .	$qd/V$ . Cal. per c.c. per $^{\circ}\text{C}$ .
6.2	4	$1.88 \times 10^{-4}$
13.7	9	$1.91 \times 10^{-4}$
20.5	12	$1.75 \times 10^{-4}$
27.3	18	$1.92 \times 10^{-4}$
41.0	25	$1.78 \times 10^{-4}$
Mean value		$1.85 \times 10^{-4}$

*Comparisons with Furnas' Results.*

Furnas' results gave a mean value of  $qd/V$  equal to about  $0.86 \times 10^{-4}$  cal. per c.c. per  $^{\circ}\text{C}$ ., about half the present value.

In comparing his experimental curves with Schumann's theory, Furnas plotted  $(t_g' - t_0)/(t_g - t_0)$  against  $\log \tau$  or  $\log z$  for the experimental and theoretical results, respectively. This method of comparison is mainly a comparison of the slopes of the central parts of the curves, which vary little for different values of  $y$ , and it is liable to lead to considerable error.

## CONCLUSIONS FROM EXPERIMENTS.

The correlation of the results in Figs. 13 to 16 proves that, for the conditions of the experiments, the rate of heating up of the bed is governed only by  $V\tau c'/dc$  and  $h/d$ , and is therefore independent of the conductivity,  $k$ , of the particles.

Theory indicates that the rate of heating up should in general depend also upon  $Vc'd/k$ , which may, however, be neglected if  $d$  is small enough, or  $k$  large enough, for the effects of temperature differences within the particles to be negligible. It thus appears that such temperature differences had a negligible effect in all the present experiments.

The highest value of  $Vc'd/k$  in the experiments was about 4, and Figs. 7 and 8 may, therefore, be used for beds of any material the physical properties of which are known, provided that  $Vc'd/k$  does not exceed this value. For example, Figs. 7 and 8 may be used for glass balls of diameters up to 0.25 in. with an air velocity of 2 ft. per sec., or for steel balls of diameters up to 11.0 in. with the same air velocity. If the curves are used for larger sizes, the calculated values of the heat transfer will be too high, but rough theoretical estimates show that the errors are probably only a few percent. for sizes up to two or three times those quoted.

Further experiments with larger spheres of poorly conducting material are needed to find the heat transfer for large values of  $Vc'd/k$ .

*Examples of Use of Results.*

The variation of gas temperature through any given bed at any time after the start of heating, may be calculated from Fig. 7. The only condition to be satisfied is that  $Vc'd/k$  must not much exceed 4.

For example, consider a bed of 2.5-in. dia. iron balls of specific heat,  $c$ , equal to 55 B.Th.U. per cu. ft. per  $^{\circ}\text{F}$ ., through which are passed 12.5 lb. of air per min. per sq. ft. of cross-section of bed. Suppose that the air enters at  $400^{\circ}\text{F}$ . and the initial temperature of the bed is  $100^{\circ}\text{F}$ . Then :

$$Vc' = V\rho's' = 12.5 \times 0.243 = 3.04 \text{ B.Th.U. per cu. ft. per min.}$$

(assuming the mean value of  $s'$  for air between  $100^\circ\text{F.}$  and  $400^\circ\text{F.}$  to be 0.243).

Taking  $k$  for iron as 30 B.Th.U. per ft. per hr. per  $^\circ\text{F.}$ , this gives :

$$\frac{Vc'd}{k} = \frac{3.04 \times 60 \times 2.5}{30 \times 12} = 1.27,$$

which is below 4, showing that the present results are applicable.

Consider the gas temperature at, say, a depth of 50 in. into the bed at 60 min. after the start of heating. Putting  $\tau = 60\text{ min.}$ ,  $h = 50\text{ in.}$ ,  $f = 0.38$  :

$$\frac{V\tau c'}{hc(1-f)} = \frac{3.04 \times 60 \times 12}{50 \times 55 \times 0.62} = 1.28,$$

and  $\frac{h}{d} = 20.$

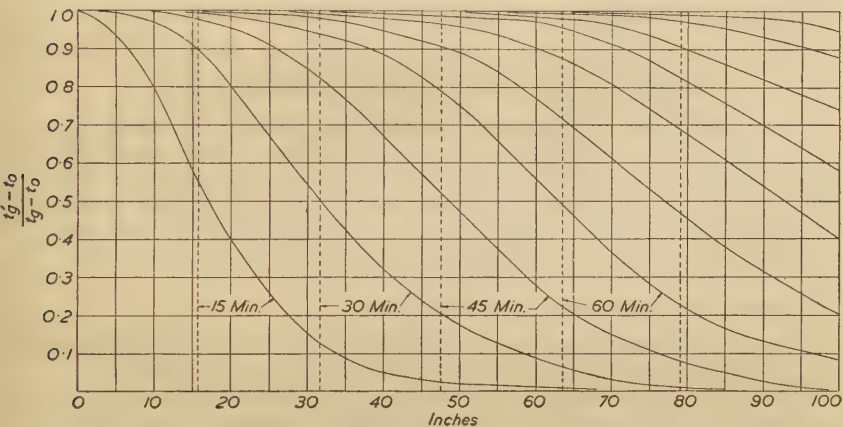


FIG. 9.—Variation of Gas Temperature through a Bed of Iron Balls, details in text.

Hence, from Fig. 7,  $(t_g' - t_0)/(t_g - t_0) = 0.73$ , and putting  $t_g = 400$ ,  $t_0 = 100$ , this gives  $t_g' = 320^\circ\text{F.}$ , which is the required gas temperature.

By calculations similar to the above, Fig. 9 has been drawn, showing the variations of gas temperature through the bed at different times from the start of heating.

Fig. 9 may be used for beds of any depth up to 100 in. Thus, for a bed 50 in. deep, the parts of the curves to the right of 50 in. have no significance, and are to be ignored.

Fig. 9 may also be applied to different materials, velocities or voidage fractions, by remembering that the time taken for any given temperature to be reached at any given depth is proportional to  $c(1-f)/V$ . For example, if the velocity were 25 lb. per ft. per min.

instead of 12.5 lb. per ft. per min., the times indicated on the curves in Fig. 9 would be halved.

For a given depth of bed, as the particle size is decreased the curves in Fig. 9 become steeper and gradually approach the vertical, but their positions are not much altered. Thus the dotted lines represent the corresponding curves for infinitely small particles, and it may be inferred that for sizes between 0 and 2.5 in. intermediate curves would be obtained.

The use of Fig. 8 to calculate the total heat transfer to or from a bed is self-explanatory. It should be noted that the co-ordinate  $4Q/\pi D^2 hc(1-f)(t_g - t_0)$  is the ratio of the heat transfer between time 0 and time  $\tau$  to the total heat transfer between times 0 and infinity, which of course equals the heat capacity of the bed multiplied by  $(t_g - t_0)$ . For a given depth of bed, variations of particle size have little effect upon the heat transfer, as is shown by the small differences between the curves for different values of  $h/d$ .

#### RESISTANCE TO FLOW OF GAS THROUGH BED.

In each of the heat-transfer experiments already described, the resistance to flow was also determined, the pressure drop across the bed being measured by either a U-tube, an inclined gauge or a Chattock gauge, according to the range. In Fig. 10 the results are shown with  $[(p_1 - p_2)gd]/(h\rho'V^2)$  and  $V\rho'd/\mu'$  as co-ordinates, as in the usual correlation of data on flow through pipes.

#### *Comparison with Previous Measurements.*

Many experimenters have studied the resistances of beds of particles, and among them the following used beds of spheres:

Blake<sup>(3)</sup> used 0.125-in. dia. beads through which air, carbon dioxide and water were passed at Reynolds numbers from 26 to 300, but he gave no particulars of the shapes of his beads or the size of the bed.

Burke and Plummer<sup>(4)</sup> used lead shot of diameters 0.15, 0.30, and 0.635 cm. in tubes of diameters 1.8 to 7.81 cm., through which air saturated with water vapour was passed at 27° C.

Furnas,<sup>(2)</sup> as part of his study of broken solids, used lead shot of diameters 0.138 to 0.905 cm. in tubes 5.19 to 15.6 cm. wide at air speeds of from 10 to 180 cm. per sec.

Chilton and Colburn<sup>(5)</sup> used spheres of diameters 0.9 in. and 1.0 in., and also pellets and granules of diameters from 0.125 to 0.56 in., in tubes of diameters 3 and 1.25 in., through which air was passed at Reynolds numbers from 500 to 9000.

Fancher and Lewis<sup>(6)</sup> used lead shot of diameter 0.1 cm. in a tube of diameter 1.9 cm. through which oil was passed at Reynolds numbers from 1 to 10.

Bakhmeteff and Feodoroff<sup>(7)</sup> used six sizes of lead shot of

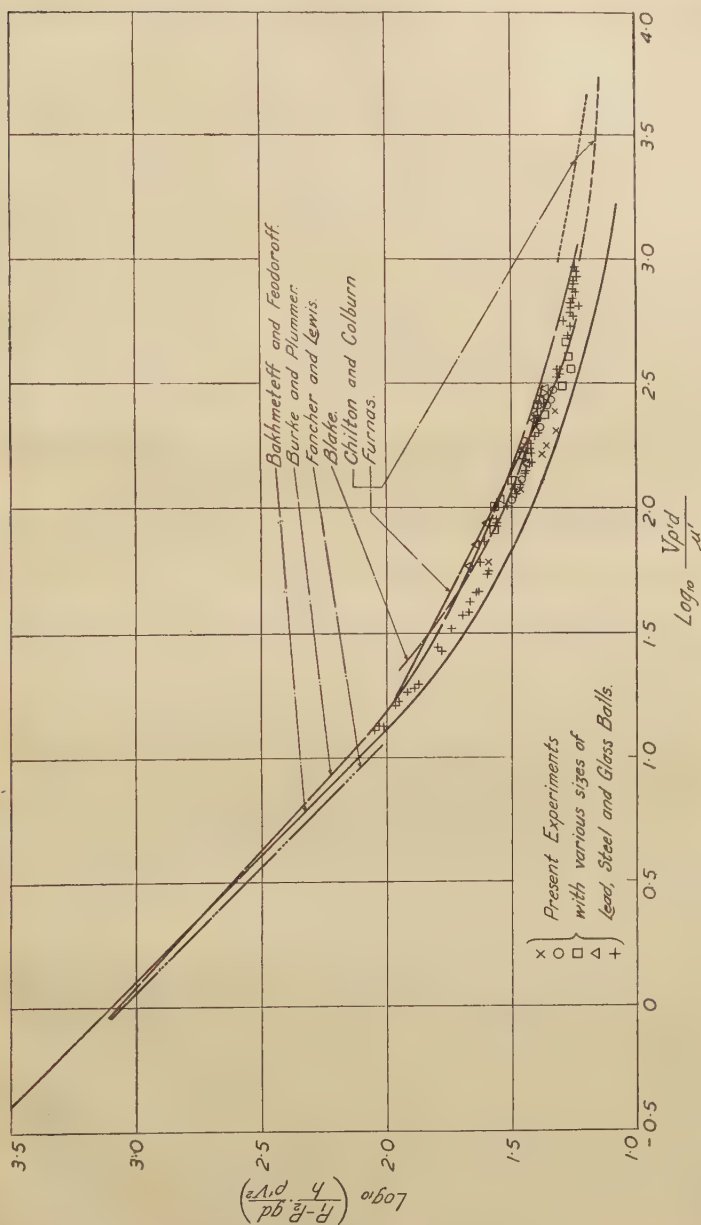


Fig. 10.—Correlated Results for Resistance to Flow through Beds. ( $+$  Steel,  $d = 0.25$  in.;  $\circ$  Steel,  $d = 0.125$  in.;  $\times$  Steel,  $d = 0.0625$  in.;  $\square$  Steel,  $d = 0.233$  in.;  $\Delta$  Glass,  $d = 0.237$  in.)



diameters 0.038 to 0.361 in., in a 3-in. dia. tube through which water was passed at Reynolds numbers from 0.1 to 8000.

All these results are compared with the present ones in Fig. 10, and the agreement is very close at low Reynolds numbers, but less close at the higher ones. Some of the results of Burke and Plummer, Furnas, and Chilton and Colburn may have been for containers too small, compared with the spheres, for the effect of the lower resistance near the walls to have been negligible. But the low values from the systematic experiments of Bakhmeteff are somewhat surprising.

There is no evidence of any discontinuity in the mean curve of Fig. 10, such as is well known to occur in the corresponding curve for flow through pipes when the flow changes from laminar to turbulent. The change-over would be expected to cause a continuous change in resistance in the case of a bed of spheres, since turbulence would not develop suddenly but would spread gradually through the bed.

For calculation purposes the mean curve may be divided into four sections:

(1) for Reynolds numbers up to 20, the equation of which is:

$$\frac{(p_1 - p_2)gd}{h\rho'V^2} = \frac{1250\mu'}{V\rho'd}.$$

(2) for Reynolds numbers between 20 and 300, the equation of which is:

$$\frac{(p_1 - p_2)gd}{h\rho'V^2} = \frac{210}{(V\rho'd/\mu')^{0.4}}.$$

(3) for Reynolds numbers from 300 to 2000, the equation of which is:

$$\frac{(p_1 - p_2)gd}{h\rho'V^2} = \frac{63}{(V\rho'd/\mu')^{0.2}}.$$

(4) for Reynolds numbers above 2000, the equation of which is:

$$\frac{(p_1 - p_2)gd}{h\rho'V^2} = 15.$$

The first region corresponds to laminar flow, the resistance being directly proportional to the velocity. The last is for highly turbulent flow, the resistance being proportional to the square of the velocity.

The work was done at the instigation of the Blast-Furnace Committee of the British Iron and Steel Federation, and was carried out with financial assistance from the Federation.

The authors would like to express their thanks to Professor C. H. Lander for his interest and help, and to the Clothworkers Company from whose grant part of the apparatus was provided.

APPENDIX I.—*Applications of the Theory of Dimensions to the Heat Transfer in Flow through a Bed of Solid Particles.*

Imagine a perfectly insulated bed of particles initially at temperature  $t_0$ , and suppose that hot gas is caused to flow continuously through the bed from time  $\tau = 0$ , entering at a constant temperature  $t_g$ . The problem is to find how the temperature,  $t'_g$ , of the gas leaving the bed varies with time as the particles gradually heat up from  $t_0$  to  $t_g$ , because from this, knowing the rate of flow and the specific heat of the gas, the heat transfer in any interval of time can readily be calculated.

Suppose that, to start with, attention is confined to geometrically similar beds, that is to say, arrangements which, though of different sizes, have the same relative proportions in every detail. For such a system of beds, the temperature  $t'_g$  would, for the reasons amplified below, be expected to depend upon :

- $l$ , the linear size of the bed, for which any convenient dimension may be taken,
- $Ms'$ , where  $M$  is the mass of gas flowing through the bed in unit time, and  $s'$  is the specific heat per unit mass of gas at constant pressure,
- $c$ , the specific heat per unit volume of the material of the particles,
- $k$ , their thermal conductivity,
- $\alpha$ , the heat-transfer coefficient per unit temperature difference per unit surface area between the gas and the particles, and
- $\tau$ , the time.

It has been assumed that  $t'_g$  depends upon  $M$  and  $s'$  only as a product and not separately, because the heat given up by the gas stream between any two given temperatures is proportional to  $Ms'$ .

The linear velocity of the gas has been left out of the list, because it is assumed to have no effect upon  $t'_g$  except in so far as it influences  $M$  and  $\alpha$ . This will only be true provided that the time taken by the gas to travel once through the bed is small compared with the time of heating up of the bed ; in all practical applications this condition is satisfied.

The density of the material of the particles has been left out because it cannot affect the problem, except that  $c$  depends upon it. Physical properties of the gas (except  $s'$  in the product  $Ms'$ ) have been left out because they cannot affect the problem except in so far as  $\alpha$  depends upon them.

*Arrangements of Variables in Dimensionless Groups.*

The dimensions of the variables in the fundamental units of length, time, temperature and heat, respectively, are  $l$  (1, 0, 0, 0),

$Ms'$  (0, -1, -1, 1),  $c$  (-3, 0, -1, 1),  $k$  (-1, -1, -1, 1),  $\alpha$  (-2, -1, -1, 1), and  $\tau$  (0, 1, 0, 0).

Assuming a general dimensionless group of the form  $l^{x_1}(Ms')^{x_2}c^{x_3}\alpha^{x_4}k^{x_5}\tau^{x_6}$  where  $x_1$ , &c., are indices to be determined, and equating to zero the dimensions of this group in terms of each of the fundamental units in turn :

$$\begin{aligned} x_1 - 3x_3 - 2x_4 - x_5 &= 0 \\ -x_2 - x_4 - x_5 + x_6 &= 0 \\ -x_2 - x_3 - x_4 - x_5 &= 0 \\ x_2 + x_3 + x_4 + x_5 &= 0. \end{aligned}$$

The last two equations being identical, the six unknown indices reduce to three. Solving for  $x_1, x_2, x_3$  in terms of  $x_4, x_5, x_6$  :

$$\begin{aligned} x_1 &= 2x_4 + x_5 - 3x_6 \\ x_2 &= -x_4 - x_5 + x_6 \\ x_3 &= -x_6 \end{aligned}$$

The general dimensionless group may thus be written :

$$\left(\frac{al^2}{Ms'}\right)^{x_4} \left(\frac{kl}{Ms'}\right)^{x_5} \left(\frac{Ms'\tau}{cl^3}\right)^{x_6}.$$

The temperature  $t_g'$  thus depends upon the three dimensionless groups  $Ms'/\alpha l^2$ ,  $Ms'/kl$ ,  $Ms'\tau/cl^3$ , and of course upon  $t_g$  and  $t_0$ . But if  $\alpha$  be assumed independent of temperature, the heat transfer being therefore proportional to the temperature difference between the gas and the particles, the temperature difference,  $(t_g' - t_0)$ , between the gas leaving the bed and the initial temperature of the bed will, other quantities being fixed, be proportional to the initial temperature difference  $(t_g - t_0)$ . Hence, in general, the ratio  $(t_g' - t_0)/(t_g - t_0)$  is a function of the three groups.

It is more convenient to express the above results in terms of the mean linear velocity of the gas,  $V$ . Since, for geometrically similar beds,  $Ms'$  is proportional to  $Vl^2c'$ , where  $c'$  is the specific heat of the gas per unit volume at constant pressure :

$$\frac{t_g' - t_0}{t_g - t_0} = f\left(\frac{Vc'}{\alpha}, \frac{Vlc'}{k}, \frac{V\tau c'}{lc}\right) \quad \dots \quad (6)$$

where  $f$  is an unknown function.

Equation (6) may be further simplified by using the relation :

$$\frac{\alpha l}{k'} = C \left(\frac{Vl}{\nu'}\right)^n, \quad \dots \quad (7)$$

where  $C$  and  $n$  are constants, and  $k'$  and  $\nu'$  are respectively the conductivity and kinematic viscosity of the gas. This relation is known to hold good for gases for all types of forced convection heat transfer, such as the flow through tubes or channels, the constant  $n$  usually lying between 0.8 and 1.0, and it is, therefore,

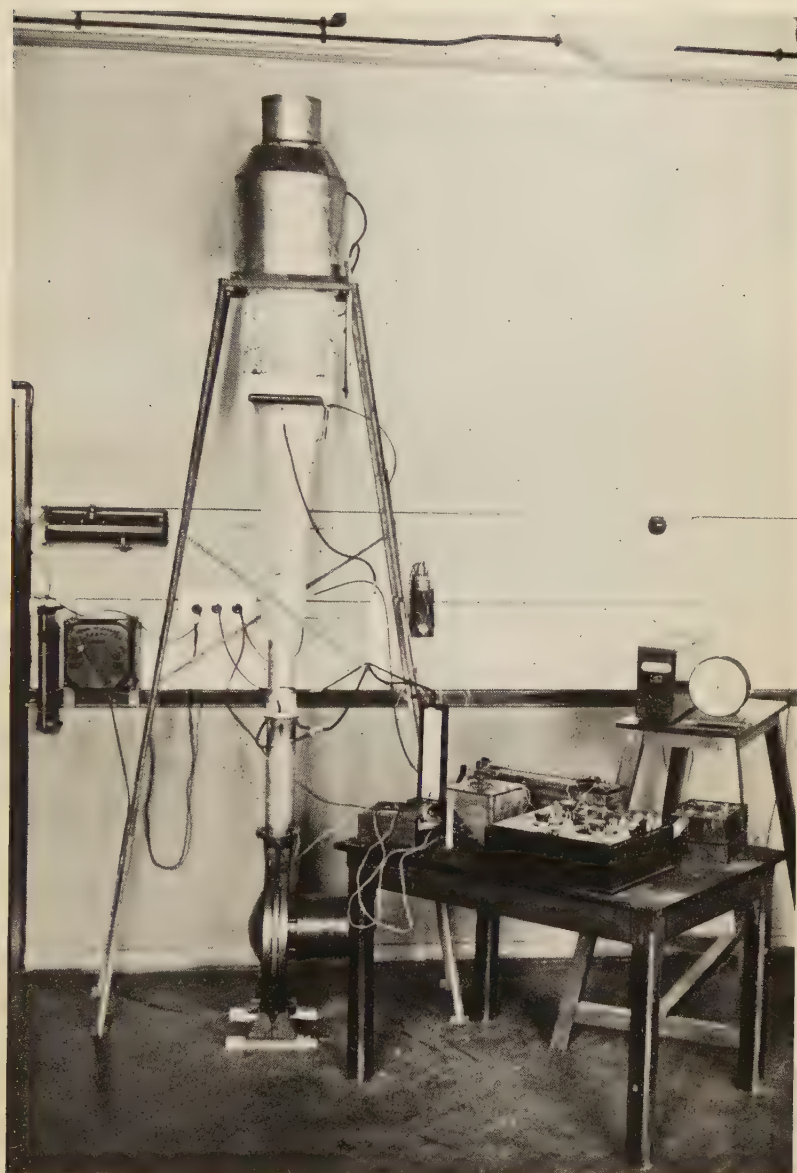


FIG. 11.—Apparatus, with 8-in. container in position.

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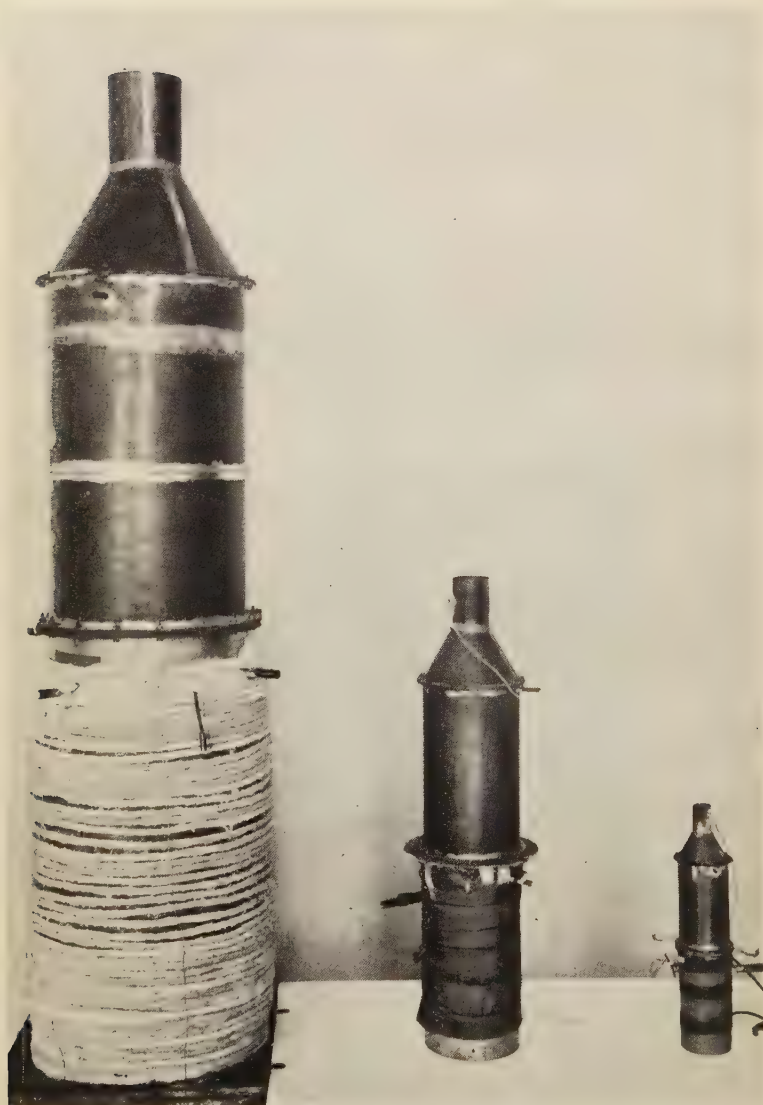


FIG. 12.—The Three Containers.



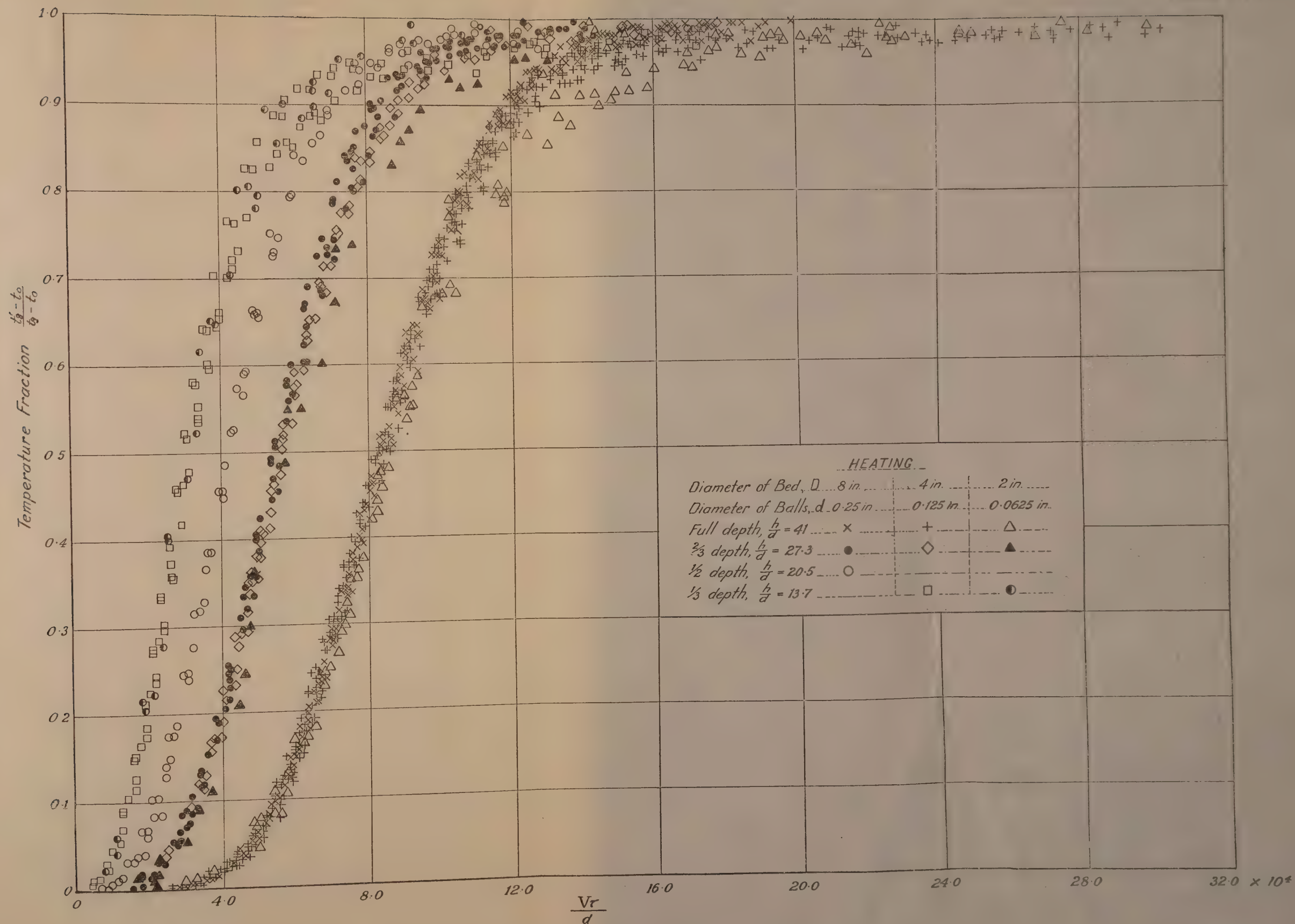


FIG.13.—Correlated Results for Steel (heating).



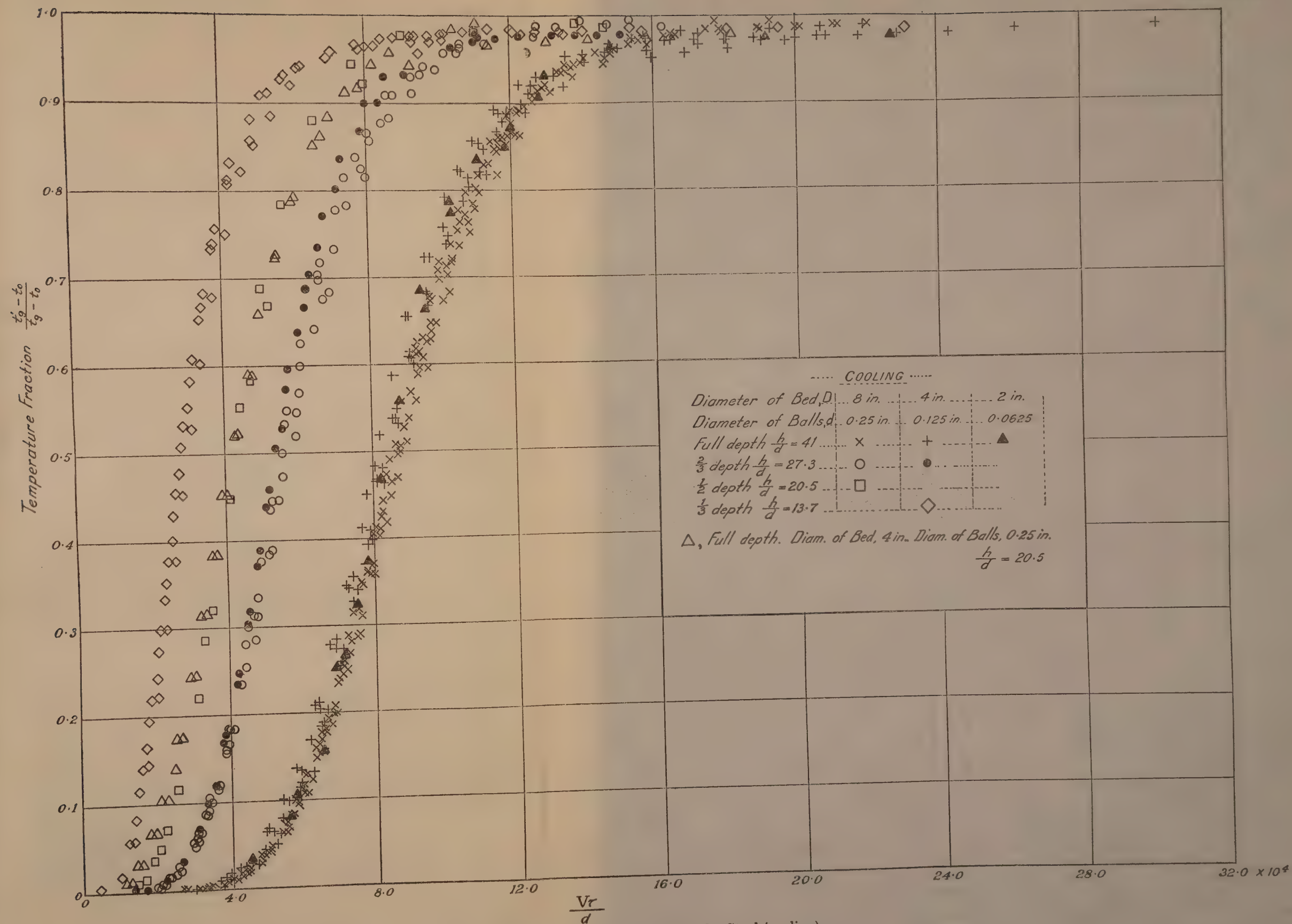


FIG. 14.—Correlated Results for Steel (cooling).





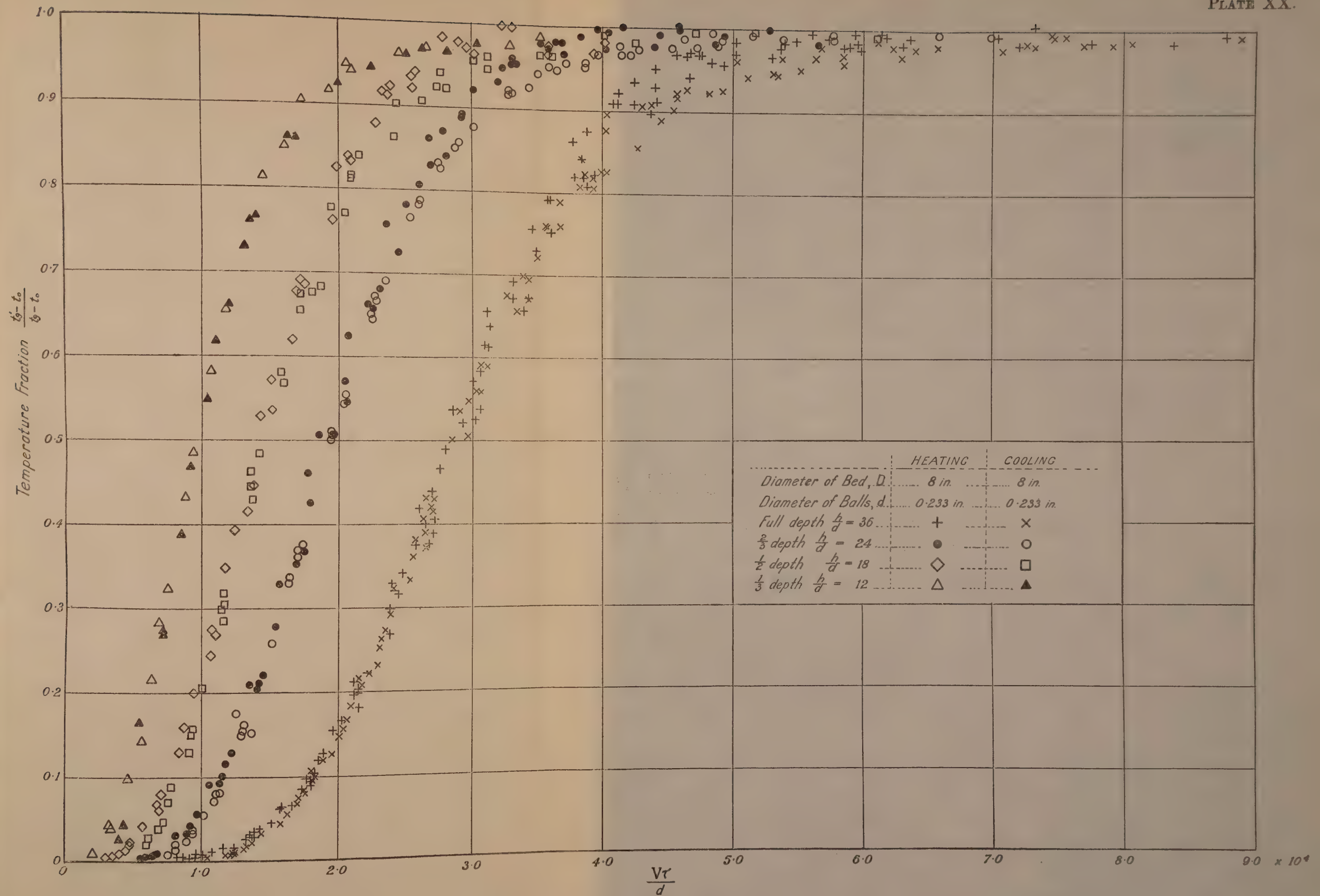


FIG. 15.—Correlated Results for Lead (heating and cooling).





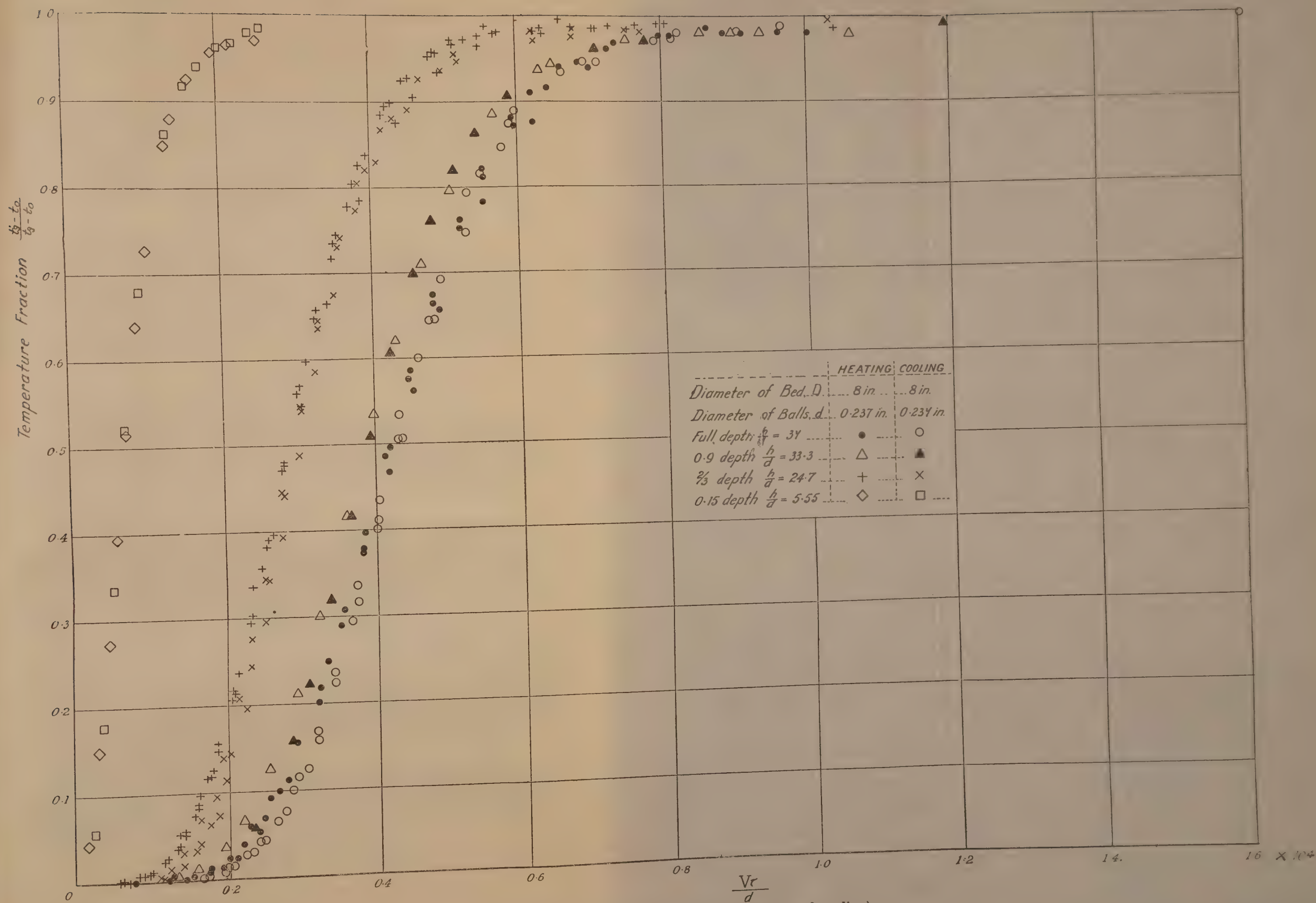


FIG. 16.—Correlated Results for Glass (heating and cooling).



reasonable to suppose that it will hold good for flow of gas through the interstices of a bed of solid particles. From equation (7) :

$$\frac{Vc'}{\alpha} \text{ is proportional to } \left(\frac{Vl}{v'}\right)^{1-n} \left(\frac{c'v'}{k'}\right) \quad . \quad . \quad . \quad (8)$$

and since  $c'v'/k'$  is known to be practically constant for any gas, and to vary little from one gas to another,  $Vc'/\alpha$  in (6) may be replaced by  $Vl/v'$ .

In particular, if  $n$  be assumed equal to 1.0, expression (8) gives  $Vc'/\alpha = \text{constant}$ , and (6) becomes :

$$\frac{t_g' - t_0}{t_g - t_0} = f\left(\frac{Vlc'}{k}, \frac{V\tau c'}{lc}\right) \quad . \quad . \quad . \quad . \quad (9)$$

#### *Case when Particles are Small or have High Conductivity.*

If the particles are small, or have high conductivity, there will be no appreciable temperature differences in their interiors, and changes in their conductivity  $k$  must be without appreciable effect. Hence  $Vlc'/k$ , which then becomes small, can be omitted from equation (9), and :

$$\frac{t_g' - t_0}{t_g - t_0} = f\left(\frac{V\tau c'}{l}\right) \quad . \quad . \quad . \quad . \quad (10)$$

#### *Heat Transfer Between Gas and Particles.*

It also follows, by similar arguments, that if  $Q$  denotes the total heat transfer from the gas to the particles between zero time and time  $\tau$ ,  $Q/Q_\infty$  is a function of the same dimensionless groups as is  $(t_g' - t_0)/(t_g - t_0)$ , where  $Q_\infty$  is the value of  $Q$  for  $\tau$  infinite.

#### *Geometrically Similar Beds in Practice.*

Although, strictly speaking, the patterns of geometrically similar beds ought to be identical in every detail, the mean rise in temperature of the gas in its passage through the bed is not likely to be appreciably affected by slight deviations from the correct pattern. Even in special experimental apparatus it would be very difficult to ensure that each particle is correctly placed.

Beds of particles of any one size and shape can probably be regarded as geometrically similar for present purposes and the results of the previous paragraphs applied to them, if the containers are of similar shape and if the sizes of particle and container are proportionate, provided that in constructing the bed a similar method of introducing the particles is used for all the containers.

#### *Spheres in Cylindrical Containers.*

For a bed of spheres, all of diameter  $d$ , in a vertical cylinder of diameter  $D$  and height  $h$ , the conditions for approximate geometric similarity are that  $h/d$  and  $D/d$  must be constant. Hence, by equation (9), for all such beds, writing  $l = d$ ,

$$\frac{t_g' - t_0}{t_g - t_0} = f\left(\frac{V\tau c'}{dc}, \frac{Vdc'}{k}, \frac{h}{d}, \frac{D}{d}\right) \quad . \quad . \quad . \quad (11)$$

and also

$$\frac{Q}{Q_{\infty}} = \frac{4Q}{\pi D^2 h c (1-f)(t_g - t_0)} = f \left( \frac{V \tau c'}{dc}, \frac{V dc'}{k}, \frac{h}{d}, \frac{D}{d} \right) \quad (12)$$

where  $f$  is the "fractional voids," or proportion of the volume of the bed not occupied by particles.

### *Velocity and Temperature Distributions.*

For similarity, the distributions of gas velocity and temperature at the inlet to the bed must, if not uniform, be kept similar in the different beds. This being so, and the other requirements for similarity already discussed also being satisfied, the distributions of velocity and temperature everywhere in the bed will be similar in the different beds at corresponding times. Corresponding times are, of course, to be calculated from the constancy of  $V \tau c' / dc$ .

In applying equations (9) to (12), the temperature  $t_g'$  may therefore be taken at *any* point in the bed, provided that the corresponding point is taken in each bed; alternatively, it may be taken as the mean temperature of the gases leaving the bed.

### APPENDIX II.—*Distributions of Velocity and Temperature over Cross-Sections of Bed.*

At the inlet cross-section the air temperature near the side ( $t_3$ ) was always within less than 5% of that at the centre ( $t_2$ ) (see Fig. 1). At the cross-section just above the balls the temperature was measured at five positions and found to be uniform within 2½%.

The velocity distribution was measured by a movable Pitot tube just above the bed. The readings were somewhat erratic, owing to the jets of air from the interstices, but the mean velocity was uniform over the cross-sections, except in an annulus within about one ball diameter from the wall, where it was about 50% higher than elsewhere.

### APPENDIX III.—*Heat Loss from Container to Surroundings.*

The rate of heat loss from the container to the surroundings at the end of several runs was estimated by two methods. First, the temperature drop across the insulations was measured at the top and bottom of the container, and, knowing the conductivity, the heat loss was calculated to be about 5 cal. per sec. for an inlet air temperature of 100° C. and surroundings at 16° C. Secondly, the average temperature of the exposed surface was measured by thermocouple and found to be 30° C. Assuming appropriate coefficients of radiation and convection, this gave the loss as about 4.0 cal. per sec. For a velocity of 1.5 ft. per sec., this represents about 1% of the total heat carried into the container by the gas,



and means that the ultimate value of  $(t_g' - t_0)/(t_g - t_0)$  is about 0.99. The correction is thus very small for this speed, which is about the average for the runs. At lower speeds the correction would be higher, but it is hardly worth correcting each run separately.

At the same velocity, the heat loss was the same percentage of the heat carried into the container by the gas, for similar beds of all three sizes.

#### APPENDIX IV.—*Calibration of Orifice Used for Measuring Rate of Flow.*

The orifice was constructed according to the standard directions given in the Verein deutscher Ingenieure "Regeln für die Durchflussmessung mit genormten Düsen und Blenden," and the standard calibration formula was used. Four different sizes, 0.482, 0.998, 1.175 and 2.512 in., respectively, were used to cover the whole range of air volume.

It is interesting that the calibration was compared with the velocities calculated from the electrical energy supplied to the air heaters and the rise in temperature of the air passing over them, knowing the specific heat of the air. The maximum difference between the two methods was 4%, the velocities deduced from the electrical energy being always higher than those calculated from the orifice formula; the difference was presumably due to heat losses from the air, which could not be avoided since a rise in air temperature of at least 10–15° C. was necessary for accurate measurement.

#### APPENDIX V.—*Corrections Applied in Drawing Figs. 6 to 8.*

(a) In the initial Figs. 3 to 5 and 13 to 16 the ratio  $(t_g' - t_0)/(t_g - t_0)$  has been expressed as a ratio of millivolts, to save converting every separate reading to temperature. But in Figs. 6 to 8 a small correction has been made so as to give the ratio as a ratio of temperatures.

(b) In the experiments the maximum values of  $h/d$  were slightly different for steel, lead or glass, being 41, 36 and 37, respectively. For comparisons in Figs. 6 to 8, the lead and glass results have been extrapolated a small amount so as to give values for  $h/d = 41$ .

(c) The container has a certain heat capacity, although small compared to that of the bed, and since it becomes heated along with the balls its presence is equivalent to a small addition to the heat capacity of the bed. Since  $c$  occurs in the denominator of the abscissa in Figs. 6 to 8, the capacity of the container was allowed for by reducing all abscissæ by a proportion equal to the ratio of the capacities of container and bed; the correction for steel balls amounted to 1.8%.

(d) The container loses heat to the surroundings during the heating or cooling of the bed. Preliminary experiments showed that the heat losses had the effect of reducing  $(t_g' - t_0)/(t_g - t_0)$  by about 1%, and the experimental values have accordingly been increased by this amount.

## LIST OF SYMBOLS.

$l$	Characteristic linear dimension.
$d$	Diameter of balls.
$D$	Diameter of container.
$h$	Depth of bed.
$f$	Space between particles, as a fraction of volume of bed.
$\tau$	Time.
$V$	Mean linear velocity of gas entering bed, reckoned at 17° C.
$\nu'$	Kinematic viscosity of gas.
$k'$	Conductivity of gas.
$\mu'$	Viscosity of gas.
$\rho'$	Density of gas.
$s'$	Specific heat of unit mass of gas at constant pressure.
$c'$	Specific heat of unit volume of gas at constant pressure.
$c$	Specific heat of unit volume of material of particles.
$k$	Conductivity of particles.
$a$	Coefficient of heat transfer per unit surface of particles.
$q$	Coefficient of heat transfer per unit volume of bed.
$t_0$	Initial temperature of bed.
$t_g$	Temperature of gas entering bed.
$t_g'$	Temperature of gas leaving bed.
$p_1$	Pressure of gas entering bed.
$p_2$	Pressure of gas leaving bed.
$M$	Mass of gas passing through bed per unit time.
$Q$	Heat transfer between gas and particles between time 0 and time $\tau$
$Q_\infty$	Heat transfer between gas and particles between times 0 and $\infty$ .

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*DISCUSSION.*

Dr. E. GREGORY (Rotherham) said the paper was the result of work done on behalf of the Blast-Furnace Reactions Committee of the British Iron and Steel Federation, and Mr. Clements, the Chairman of that Committee, was unfortunately unable to be present. His absence, however, did not imply any lack of appreciation of the authors' work; on the contrary, he had expressed the hope that they would go further and apply the results of their experiments to actual industrial problems.

The question of heat transfer during the flow of gases through a bed of solid particles was of importance in connection not only with the flow of gases through the interstices of the constituents of a blast-furnace burden but also with the flow of gas through the coke and coal beds of reheating furnaces and of gas producers and so on. In their experiments, the authors had used steel, lead and glass balls, and it might be asked what was the relationship of their present experimental results on those materials to actual blast-furnace practice. They had probably selected glass as a typical non-metallic constituent, and the steel and lead balls as typical of metals. There was, however, one point in particular which should be emphasised, namely, the fact that in actual blast-furnace practice the composition of the reduced iron, for instance, varied continuously as it descended the furnace. At first it was relatively pure, but it absorbed carbon as it descended, and this must have an influence on its thermal conductivity.

The influence of thermal conductivity, as the authors had pointed out, had been regarded as negligible in the present series of experiments, but in actual blast-furnace practice the size of the materials descending the furnace considerably exceeded that of the  $\frac{1}{4}$ -in. dia. balls used by the authors. In practice, therefore, it would seem that considerable temperature gradients must exist in the materials of the blast-furnace burden, and the question of thermal conductivity must then become one of considerable importance in regard to heat transfer. Its influence would also depend, of course, upon the temperature of the gases entering each or any particular bed. Incidentally, although the authors stated that this fractional drop in most of their experiments was about 84° C., he had not found in the paper any indication of the initial temperatures of the air entering the beds of steel, lead and glass balls, respectively.

He would like to express his admiration of the authors' excellently-devised apparatus and of their mathematical treatment of the problem which they had set themselves. It was to be hoped that it would be possible for them to continue their work and apply it directly in practical industrial processes.

Mr. T. F. RUSSELL (Sheffield) said that he had read the paper with interest and admired the authors' efforts to correlate their experimental results with theory. The authors had, in effect, shown experimentally that for geometrically similar beds, under the particular conditions of their experiments, the time for the "fractional temperature"  $(t_g' - t_0)/(t_g - t_0)$  of the outgoing gas to reach some agreed value, and the time for the fractional quantity of heat  $Q/Q_\infty$  in the solid to reach some agreed value, both varied directly as the diameter of the balls and inversely as the velocity of the gas. They had then attempted to show, by an ingenious use of the theory of dimensions, that such a result could be expected. He would call this conclusion (1). It was upon this theoretical aspect of the work that he wished to comment.

The authors had deduced that the fractional temperature could be expressed as a function of the three dimensionless groups given in their equation (6). Any other dimensionless group could be included, as was done in equation (11). The constancy of any of these groups fixed the experimental conditions, and with this reservation need not be considered further in the functional expression. For example,  $h/d$  and  $h/D$ , being constants, defined geometrically similar conditions, and the experimental results must be dealt with in sets, as had been done by the authors, each set having a different value of  $h/d$  and  $h/D$ . To be strictly accurate a dimensionless group could be eliminated only if its value were zero, or a constant quite independent of experimental conditions. The authors' reason for eliminating  $Vc'/\alpha$  was satisfactory if  $n = 1$  in equation (7), but their reasons for eliminating  $Vlc'/k$  were not easy to follow. The values of  $V$ ,  $l$  and  $c'$  were the same as those in the third group; time varied with  $V$  and  $l$ , and the numerical values of  $Vlc'/k$  for steel and glass might be in a ratio as high as 50 to 1. Some better reason for rejecting this term therefore seemed to be necessary.

In the authors' experimental work, they were dealing with a condition of "unsteady" temperature, and the thermal property which was of importance in the study of heat flow during unsteady temperature conditions was the thermal diffusivity,  $a^2 = k/c$ . Had the authors used this quantity in their dimensional treatment of the problem they would have arrived at the result:

$$\frac{t_g' - t_0}{t_g - t_0} = F\left(\frac{l^2 a}{Ms'}, \frac{a^2 \tau}{l^2}\right),$$

or, by again putting  $Ms'$  proportional to  $Vl^2c'$  and  $a^2 = k/c$ :

$$\frac{t_g' - t_0}{t_g - t_0} = F\left(\frac{Vc'}{a}, \frac{k\tau}{cl^2}\right).$$

A more satisfactory treatment was to rewrite the authors' groups in the more complete form:



$$\frac{(t_g' - t_0)}{t_g - t_0} = \sum_{x_4 x_5 x_6} \left(\frac{Vc'}{a}\right)^{x_4} \left(\frac{Vlc'}{k}\right)^{x_5} \left(\frac{V\tau c'}{lc}\right)^{x_6} \dots \quad (a)$$

$$= \sum \left(\frac{Vc'}{a}\right)^{x_4} \left(\frac{Vlc'}{k}\right)^{x_5 + x_6 - x_6} \left(\frac{V\tau c'}{lc}\right)^{x_6}$$

$$= \sum \left(\frac{Vc'}{a}\right)^{x_4} \left(\frac{Vlc'}{k}\right)^{x_7} \left(\frac{a^2 \tau}{l^2}\right)^{x_6} \dots \quad (b)$$

where

$$x^7 = x^5 + x^6.$$

The right-hand sides of equations (a) and (b) were, of course, identities, so that if it was permissible for the authors to reject  $Vc'/a$  and  $Vlc'/k$  from equation (a), it was equally permissible to reject them from equation (b), and the conclusion could be drawn, quite logically, that the time for the fractional temperature to reach an agreed value would vary directly as the *square* of the diameter of the ball and be *independent* of the velocity of the gas (conclusion (2)). This conclusion was so far removed from the authors' experimental results that there might be a tendency to reject it without further consideration. He would, however, suggest that these two conclusions applied to the two limiting cases, mentioned below, of the general problem of the transfer of heat to spheres, and he would further suggest that the true solution of the problem was that the time varied as  $d^n$  where  $n$  lay between 1 and 2, the value of  $n$  depending on the magnitude of the dimensionless group  $l\alpha/2k$ , which he would denote by  $H$ .

He (Mr. Russell) had found that such a relationship existed for the heating of steel bars in constant-temperature surroundings.<sup>1</sup>

It could also be proved that such a relationship existed for spheres heated in constant-temperature surroundings, and as this represented the condition for the first layer of bed in the authors' experiments the general conclusion would also apply.

In the notation used in the speaker's publication the partial quantity of heat in the steel balls at time  $t$  was :

$$\frac{Q_t}{Q_\infty} = \sum_{n=1}^{\infty} \frac{6}{M_n^2} \cdot \frac{H^2}{M_n^2 + H(H-1)} (1 - e^{-M_n^2 \tau})$$

where  $M_n$  = the  $n$ th root of  $M \cot M = (1 - H)$ .

$$H = \frac{\text{Radius of ball} \times \text{coefficient of heat transmission}}{\text{Thermal conductivity}}$$

$$\tau = \frac{\text{Thermal diffusivity} \times \text{time}}{\text{Radius}^2}$$

Now, from this equation it was readily proved that if  $Q_t/Q_\infty$  remained at a constant value the time required to reach this value

<sup>1</sup> First Report of the Alloy Steels Research Committee, p. 146, *Iron and Steel Institute*, 1936, *Special Report No. 14*.



approached direct proportionality to  $d$  as  $H$  approached zero; and the time approached proportionality to  $d^2$  as  $H$  approached infinity, i.e.,  $n$  varied from 1 to 2 as  $\lambda\alpha/2k$  varied from 0 to  $\infty$ .

It would appear therefore that the reason why the authors found that time was proportional to the diameter was that in their experiments the quantity  $\lambda\alpha/2k$  was small; the greater  $\lambda\alpha/2k$  became the more the deviation from direct proportionality would become.

Mr. T. HENRY TURNER (Doncaster) asked the authors how it was possible to avoid the consideration of skin friction. It was possible that skin friction did come into their calculations under kinematic viscosity or some other name, but the surface of the particles was surely of importance, and the term "skin friction," which was familiar in aeronautics, must mean that heat could be generated. In the authors' calculations there seemed to be no reason why the curves should not be transposed one way or the other, depending on the work done in pushing the air between the particles. Perhaps the authors would explain whether the conception of skin friction was ignored entirely; if it was not ignored, then when one turned from relatively smooth balls to the always irregular rough particles of cupolas and blast-furnaces, it would be interesting to know how that change in skin friction would affect their curves.

Dr. P. O. ROSIN (London) said he had studied the authors' paper with great pleasure, and he thought that their model tests really were a model of how a difficult problem should be tackled. By limiting the scope of their investigations, instead of being too ambitious from the outset, they had gained a full success where others had failed. Also, by applying the laws of dynamic similarity, which were by now indispensable, the authors were able to extract from the data obtained information of general value.

The paper was particularly interesting to him, as on several occasions he had had to deal with various effects of fluid flow on a bed of solid material.

The authors concluded from their experiments that the conductivity of the solid particles had no influence on the heat transfer if  $Vc'd/k$  did not exceed 4. This was very important, though not very surprising, as it corresponded to similar experience in other cases. He even thought that the value of 4 as an upper limit was very conservative. He would not hesitate to say that up to values of 30 or 40 no appreciable influence of conductivity in a technical sense was likely to be found. In any case, for all applications conceivable the conductivity of the solid material would be of very minor importance.

Further, the authors had found that, apart from variables defining the geometrical arrangement of the bed, the heat transfer was governed by one dimensionless group only, namely,  $V\tau c'/dc$ .

What did this mean? In the first instance it meant that the only properties of the material involved which mattered were their specific heats. That was to say that neither the conductivity, both of the particle and the gas, nor their density, nor the viscosity of the gas had any influence on the process. This was a most interesting result, because it literally meant that all the properties representing the capability of the materials to exchange, by molecular movements, a certain amount of energy per unit time had no influence whatever on the rate of heat transfer. This was not as absurd as it sounded, for one ought to remember that the values given for these properties represented, if he might say so, the limits of the transport facilities available. And if these limits did not come in, it meant that these facilities were ample in proportion to the heat to be carried into the particle and did not put any restriction upon the process.

If this were the case, there was obviously only one limit to this transport process, namely, the capacity of the bed to store heat in relation to the amount of heat carried into it by the flow. That was exactly what the dimensionless group  $V\tau c'/dc$  represented. The explanation why storage was the only limit to heat transfer would be that the narrowness of the channels in a bed and the great amount of artificial turbulence due to their shape gave the heat an excellent direct access to the surface. Convection seemed to be absolutely preponderant over conduction of heat. If this was the case for spheres with a polished surface, it should apply still more to broken material. One would, of course, ask for what range of Reynolds number this result held. Obviously it was difficult to see an upper limit as long as the bed remained stationary. There should, however, be a lower limit. If the experiments had been carried out down to Reynolds numbers of about 20, as Fig. 10 suggested, it would also in this respect cover the whole range conceivable in practice.

It would take too long to discuss all the implications of these results. He would only like to add one conclusion to which they had lead him regarding continuous heat transfer to a bed which moved downwards as in blast-furnaces or in gas producers. They tended to show that heat transfer and distribution of temperature in such cases were entirely governed by the ratio of the gas velocity to the velocity of the downward movement of the bed. This ratio must obviously have a bearing on the process. But what seemed to be a new discovery was that the efficiency of heat transfer and the bed temperatures, allowing for heat losses, remained constant, irrespective of load, as long as the throughput of solid material was raised in proportion to the rate of gas supply. Of course, this result did not apply to wet material, where the heat of evaporation would upset the normal distribution of temperature, and to cases in which chemical reactions between the gas and solids were likely to be influenced by their relative velocity.

This brought him to the actual value of the heat-transfer coefficient; for, evidently, this was the information most needed for industrial application. The authors had calculated an average value covering the whole process of heating-up from start to end. They had done so by comparing the experimental rise in temperature with Schumann's theory, which probably assumed a constant heat-transfer coefficient throughout the bed and from start to end. The authors did not say whether they had found any appreciable variation of the coefficient with time and place. But even if the average held for the greater part of the process, there was one very real difficulty, *i.e.*, the determination of the temperature difference between the gas and solid in conjunction with which the heat transfer coefficient had to be used. A simple calculation might illustrate that.

Taking the value of the coefficient as given in the paper, he had tried to recalculate in the ordinary way the time needed to heat up the bed under a certain set of conditions. Inserting the initial difference in temperature between the gas and bed into the calculation, one arrived at a heating time 60 times smaller than that found by experiment. The explanation was the following: (1) The average temperature drop between the gas and bed was evidently only a fraction of the initial one, and (2) the successive layers of the bed were heated up "in series," and not "in parallel." The tacit assumption usually made that the whole of the heating surface was simultaneously engaged in heat transfer did not apply in this case.

He was therefore at a loss to see how the heat-transfer coefficient as usually defined could be used practically, and he would ask the authors whether they thought it possible to derive a formula, representative of their experiments, by relating the heat transfer to the unit *volume* of solid material and to the *initial* difference in temperature between the gas and bed. If this were possible, as Table II. suggested, such a coefficient could be advantageously used for calculations, particularly if the experiments were extended to broken solids the surface of which could not well be computed.

Mr. R. L. BROWN (London) congratulated the authors on their valuable contribution to the fundamentals of heat transfer to a bed of solid particles. All who had worked on the many problems connected with granular materials would know how difficult it was to devise experimental techniques. By starting their investigation with a limited number of variables, the authors had shown clearly the influence of some of the physical properties of the gas and solid on the heat transfer. There were, however, several considerations which applied if the results were to be extrapolated to higher temperature differences, to liquids, to particles of lower thermal conductivity, to packings of different voidage ratio and to cases in which there was a heat loss to the walls.



By splitting the variables on which the heat-transfer coefficient depended into three dimensionless groups and then showing that their data could be correlated without using the group involving the thermal conductivity of the solid, the authors had shown that, within the range of their experiments, the heat-transfer coefficient was independent of the thermal conductivity of the solids. Two points arose from this conclusion. First, with regard to extrapolation to higher temperatures, Furnas' experiments<sup>1</sup> on coke showed that the cooling curve was different from the heating curve. It was suggested<sup>2</sup> that this was due to the temperature gradient in the coke particles, these not having reached a steady state. This was possible, since  $Vc'd/k$  for Furnas' experiments on coke was much greater than 4. There was, however, another possible explanation, which had been found to hold in heat transfer between heated flat plates or pipes and a gas, namely, that the heat transfer was governed mainly by the film or boundary layer on the solid body. The thickness of this film depended on the viscosity of the main stream, and therefore on the temperature of the gas. Kaye and Furnas<sup>3</sup> suggested that, on this basis, the ratio of the heating and cooling heat-transfer coefficients should equal the  $r^{\text{th}}$  power of the ratio of the main stream viscosities. They gave the values  $r = 0.5$  for liquids and  $r = 1.0$  for gases, this giving results substantially in agreement with experiment. In comparatively simple problems numerous attempts had been made, both theoretically and experimentally, to allow for the distortion of the velocity distribution by viscosity. That such distortion could materially affect the heat transfer was well established for simple systems. Since the authors had taken the heat transfer as proportional to the first power of the Reynolds number, viscosity did not enter into their method of plotting. No difference was observed between the heating and cooling curves, and this was probably because the temperature differences were small ( $84^{\circ}$  C.). For larger temperature differences, or for liquids, the heating and cooling curves might be expected to differ. Owing to these considerations errors might enter into the extrapolation of the results given in the paper to higher temperature differences, to liquids and to materials of lower conductivity.

The second point arising from the independence of the results from the thermal conductivity of the solids, was that it should be possible to relate the heat transfer to the resistance of the bed to gas flow. For steady-state problems, theory and experiment had shown that the Nusselt heat-transfer number was a function of the Reynolds number, which depended on the velocity distribu-

<sup>1</sup> Furnas, *U.S. Bureau of Mines*, 1929, *Bulletin No. 307*.

<sup>2</sup> Sherwood, *Transactions of the American Institute of Chemical Engineers*, 1930, vol. 24, p. 192.

<sup>3</sup> Kaye and Furnas, *Industrial and Engineering Chemistry*, 1934, vol. 13, p. 783.

tion, and on the Prandtl number,  $\sigma = \nu/\kappa$ , which was independent of the velocity distribution. When  $\sigma$  did not differ much from unity the Nusselt number depended on the Reynolds number alone. It would be extremely valuable if similar relations could be found for the heat-transfer coefficient and the resistance of a bed. Such relations existed for packed tubes, and might be expected to hold also during the heating-up period of beds of particles. This was possible, because in a bed of particles, particularly at high rates of flow, the resistance of the bed was due more to loss of dynamic head in impacts between the stream and the particles than to skin friction between the particles and the gas.

There was another point in connection with the statement at the bottom of p. 307 P that the time for a given temperature to be reached was proportional to  $c(1-f)/V$ . The term  $(1-f)$  came from the volume occupied by the solids, but the experiments were restricted to packings in which the voidage ratio was between 0.375 and 0.38, so that there was no direct evidence that the linear velocity based on the free area of the container should be used in the dimensionless group. That it was not sufficient to use the linear velocity based on the free area of the container had been shown in work on the resistance of beds to gas flow. It seemed more probable that the velocity used should be the interstitial velocity, obtained by dividing the volume flowing by the area of the container multiplied by the voidage ratio.

In conclusion, he would like to draw attention to one of the difficulties to be expected in attempting to extend this work to more complicated systems. An obvious practical example was one in which there was a heat loss from the walls of the cylinder. In this case the constant pressure difference between the top and bottom of the bed necessitated a larger mass flow of gas along the walls than along the axis. For example, if the axis was at 1300° C. and the walls were at 400° C., the flow along the walls in a uniformly packed bed was nearly twice that along the axis. This non-uniform velocity distribution would also affect the heat transfer coefficient from the gas to the solids. It was interesting to enquire how the radial heat flow would take place. The forced convective heat transfer was in the direction of the axis so that the radial heat transfer must be due to radiation, free convection and conduction through the particles. A simple extension of experiments by Schumann and others<sup>1</sup> would show what part radiation and free convection played. If it should be established that the radial heat transfer was due to conduction through the particles only, then it should be possible, using the authors' experiments, to calculate the heat transfer, the temperature distribution and the velocity distribution in a bed. A typical example of the velocity distribution to be expected was given in Fig. A. It was

<sup>1</sup> Schumann and Voss, *Fuel*, 1934, vol. 13, p. 249.



probable that this was the real wall effect that was so often referred

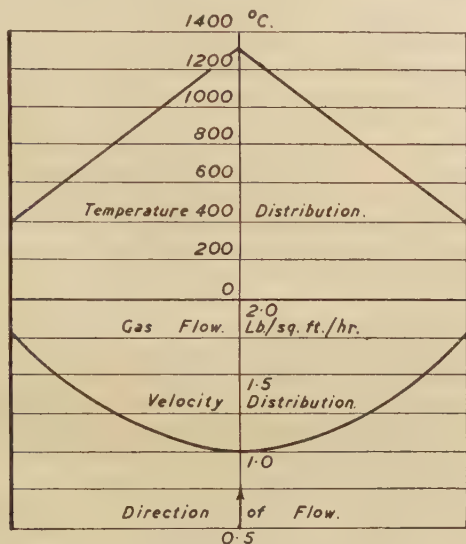


FIG. A.—Parallel-Flow Velocity Distribution due to Temperature Gradient.

to in experiments on flow through beds. It could not be observed in cold-flow experiments, as Fehling<sup>1</sup> had recently shown.

### AUTHORS' REPLY.

The AUTHORS replied that Dr. Gregory had raised the question of the influence of the thermal conductivity of the materials upon the heat transfer in a blast-furnace. This was one of the most interesting fields of application, but it was also one of the most complicated, since, as Dr. Gregory had pointed out, the conductivity was changing as the materials descended. The authors would very much like to follow up this question if Dr. Gregory could give them any data on thermal conductivities of blast-furnace materials.

The initial temperature difference between the air and the balls at the inlet to the bed was 84° C. in most of the experiments; the balls were initially at about 16° C. in the heating experiments, and at about 100° C. in the cooling experiments.

<sup>1</sup> Fehling, *Feuerungstechnik*, 1939, vol. 27, Feb. 15, p. 33.

Mr. Russell had commented on the theory in the paper, and although the authors could not quite agree with some of his arguments, they were entirely in agreement with his conclusion that "the time of heating,  $\tau$ , was proportional to the diameter in the experiments because  $l\alpha/2k$  was small." This was, in effect, stated at the top of p. 294 p, where it was said that only the group  $V\tau c'/lc$  need be considered provided the group  $Vlc'/k$  was small enough. The only difference between the two statements was that, whereas the authors used the group  $Vlc'/k$ , Mr. Russell used  $l\alpha/2k$ . Since  $\alpha$  had been taken as proportional to  $Vc'$ , the two groups were proportional, but the authors preferred  $Vlc'/k$  because it contained only known quantities, whereas  $l\alpha/2k$  could not be evaluated unless  $\alpha$  was known, which it would not be in any given practical application.

Alternative dimensionless groups could, of course, be used in place of those in the paper; such groups could, for instance, be obtained by multiplying or dividing those in the paper, but the physical significance of the results would not be affected by choosing such groups. The groups given in the paper were chosen as the simplest ones which involved only known quantities.

The reasons for eliminating  $Vlc'/k$  were physical. It was obvious that, if  $k$  were large enough, differences of temperature within the particles must be negligible and a further increase of  $k$  could not affect the heat transfer. Hence, in equation (6),  $Vlc'/k$  could be omitted in such conditions, because it was the only group containing  $k$ . The authors could not agree with Mr. Russell's argument that  $Vlc'/k$  could equally well be left out of his equation (b); for in this equation  $k$  appeared in *two* groups,  $Vlc'/k$  and  $a^2\tau/l^2$  [ $\equiv k\tau/cl^2$ ]. It was not true that the right hand sides of (a) and (b) were *identical*, because the third group was different in the two equations.

In general, as Mr. Russell had pointed out, time varied as  $d^n$ , where  $n$  lay between 1 and 2. In the limiting case when  $Vlc'/k$  was very small,  $n = 1$ , as already explained. In the other extreme case when  $Vlc'/k$  was very large,  $n = 2$ . The latter result followed immediately from equation (9) of Appendix I. For, if  $k$  were sufficiently small, the temperature differences between the air and the particle surfaces would be negligible, the problem reducing to the penetration of heat into the particles by conduction, and the heat transfer would then be unaffected by changes in the surface heat transfer coefficient; thus the heat transfer would be independent of  $V$ , and would, therefore, be governed by the quotient of the groups in (9), i.e., by  $k\tau/cl^2$ . The time  $\tau$  would then be proportional to  $l^2$ .

Mr. Turner had mentioned skin friction. So far as heat transfer was concerned, it was unlikely that roughness mattered much. This view was based not on the present experiments, but on other known data for the effect of roughness upon heat transfer. The

resistance to flow, on the other hand, would probably be considerably greater with rougher particles.

Professor Rosin had suggested that the figure of 4 given as a critical value of  $Vc'd/k$  in the paper might be raised to 30 or 40. That was a very interesting suggestion, because investigations carried out since the paper was written had led to the same conclusion; in other words, the range of applicability of the authors' results was greater than they had claimed.

The heat transfer coefficients in Table II. had been worked out by comparing the experimental results with Schumann's theory which, as Professor Rosin had remarked, assumed a constant heat transfer coefficient throughout the bed and from start to end. How far this was justified could not be decided from the present experiments in which measurements were confined to the bed as a whole. These coefficients were worked out as a matter of general interest; they could not be used to calculate the heating times under a given set of conditions, except in conjunction with Schumann's theory. If used directly in conjunction with the initial temperature difference between the air and the particles, the resulting heat transfer would certainly be much too large, and the corresponding time of heating much too small. The best way of applying the results in practice was to use Figs. 7 and 8, as was done in the example worked out on pp. 306 P and 307 P.

Replying to Mr. Brown, the authors thought it likely that extrapolation to higher temperature differences might lead to some error owing to the variation of viscosity with temperature. It should be remembered, however, that the error would probably be less than in such problems as the flow of fluids inside pipes, because the temperature differences between the gas and the particles decreased rapidly as the gas passed through the bed.

It did not seem that the heat transfer could in general be related to the friction, as was done in flow through pipes, because changes of the conductivity of the particles could not directly affect the friction but might affect the heat transfer. In the special circumstances when  $k$  was without effect on the heat transfer, as in the present experiments, it might be possible to establish such a relation, but difficulties arose in expressing the variable heat flow in suitable form. The authors were puzzled by Mr. Brown's remark that the heat transfer could be related to the resistance, "because in a bed of particles, particularly at high rates of flow, the resistance of the bed was due more to loss of dynamic head in impacts between the stream and the particles than to skin friction between the particles and the gas." It was the skin friction, and not the form drag, which was normally related to the heat transfer in flow through pipes and other heat-transfer problems.

The results given for the effect of change of the voidage fraction  $f$  had no experimental basis, but were obtained by assuming that the heat transfer depended on the interstitial velocity.

The authors were particularly interested in Mr. Brown's remarks about radial temperature differences. The present paper did not attempt to deal with such cases, which needed further experimental work. It was likely that the radial heat flow was due mostly to conduction, and it might be possible to attempt to calculate the temperature distribution in a bed for which the heat losses from the sides were known.

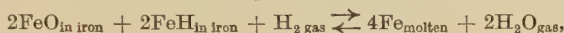
# THE OXYGEN/HYDROGEN/MOLTEN-IRON SYSTEM.\*

BY HENRY LEPP, DOCTEUR-INGÉNIEUR (DIVES-SUR-MER, FRANCE).

## SUMMARY.

In this study, the author attempts to demonstrate the co-existence in molten iron of the oxide ( $\text{FeO}$ ) and of absorbed hydrogen (hydride), his calculations being based on experimental data already published.

The process of interaction of water-vapour with molten iron seems to be capable of being represented very well by the reaction :



and the equilibrium constant of this reaction by the equation :

$$\log K = + \frac{23,586.82}{T} - 7.5526.$$

SINCE the classic researches of Sainte-Claire Deville,<sup>(1)</sup> numerous investigations have been made into the reaction of water-vapour with iron, and the experimental results obtained may now be said to show very good agreement.

Up to the melting point of iron, in particular, the variation of the equilibrium constant of the reaction :



in terms of temperature is known with a fair degree of accuracy.

This is not true for higher temperatures, however, since fewer researches have been carried out on the equilibrium of the system molten-iron/water-vapour. The constant of the reaction has usually been defined by the expression :

$$K = \frac{(\text{H}_2)}{(\text{H}_2\text{O})} = \frac{(p_{\text{H}_2})}{(p_{\text{H}_2\text{O}})},$$

that is, by the composition of the gas phases above the metal (the ratio  $p_{\text{H}_2}/p_{\text{H}_2\text{O}}$ ), thus neglecting the content of absorbed hydrogen and of oxide ( $\text{FeO}$ ) in the metal.

It is only in recent years that the significance of the reactions :



has been appreciated in their bearing on steel manufacture (forma-

\* Received October 11, 1939.



tion and nature of the flakes, occluded gases, the influence of hydrogen on the properties, &c.) and that they have been further investigated.

Special mention may be made of the quantitative researches of Vacher and Hamilton <sup>(2)</sup> and of Vacher <sup>(3)</sup> in connection with the reactions (1) and (2) above, and it is these that will be specially dealt with in the course of this paper. The author would also mention the remarkable researches of Chipman, <sup>(4)</sup> Fontana and Chipman <sup>(5)</sup> and Chipman and Samarin. <sup>(6)</sup>

Owing to the fact that these workers were able to utilise improved methods and apparatus, the results of their experiments agree very satisfactorily with each other, while at the same time spectroscopic analysis has enabled the thermodynamics of these reactions to be placed on an increasingly accurate basis and in this way has facilitated their study. <sup>(7)</sup>

Chipman and Samarin have defined the constant of the reaction :



by :

$$K_1 = \frac{(\text{H}_2\text{O})}{(\text{H}_2)(\% \text{ O})} \text{ and } K = \frac{(\text{H}_2\text{O})}{(\text{H}_2)(\% \text{ FeO})}.$$

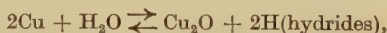
Obviously the equilibrium constant obtained by these writers is much more accurate, and gives a much more complete idea of the actual mechanism of the reaction than the constant expressed by the formula :

$$K = \frac{(\text{H}_2)}{(\text{H}_2\text{O})}.$$

In the above work, however, the absorption of hydrogen by the metal was neglected, and only the concentration of the hydrogen above the metal was considered.

This interpretation is not accurate, since the analysis of the gases extracted from the steel reveals the co-existence of oxygen and hydrogen. Moreover, the researches of Allen and Hewitt <sup>(8)</sup> and of the present author <sup>(9)</sup> have shown the simultaneous presence of oxygen and hydrogen, or, rather, of the oxide and the hydride, in molten copper and nickel (*see* Fig. 1).

The experimental results agree very well with the thermodynamical calculations based on a study of the reactions :



This paper, which is based on experimental results, therefore attempts to show that this co-existence of oxygen and hydrogen exists in molten iron also.

The system molten-iron/hydrogen will be dealt with first.

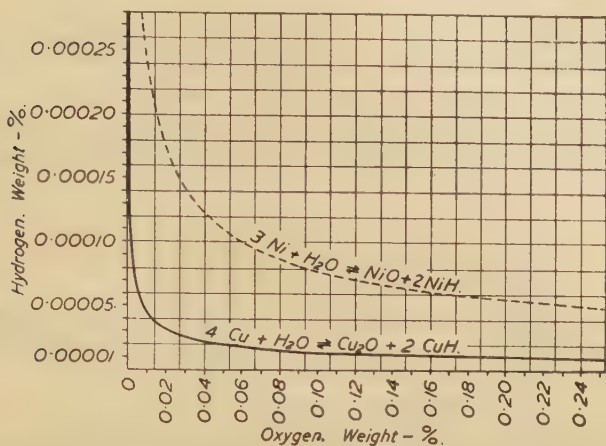


FIG. 1.—Co-existence of Oxide and Hydride in Copper and Nickel.

The fundamental researches of Sieverts, summarised in Fig. 2, have shown that the absorption obeys the law :

$$M = K_1 \sqrt{p},$$

where

$M$  = quantity of gas absorbed,

$K_1$  = characteristic constant for the gas/metal system considered,  
which also depends on the temperature,

$p$  = gas pressure.

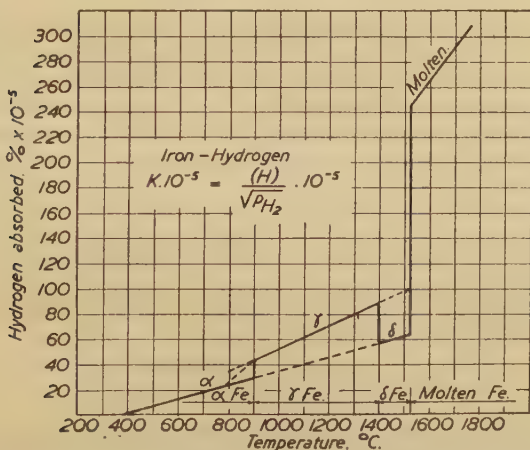


FIG. 2.—Absorption of Hydrogen by Iron in Dependence on the Temperature.

Expressed differently, this means that the amount of hydrogen absorbed by the iron is proportional to the square-root of the pressure.

The author has also been able to show <sup>(10)</sup> that Sieverts' law was only a specific instance of the law of mass-action, and that Sieverts' constant was equal to the square-root of the equilibrium constant of the gas/metal system :

$$K_1 = \sqrt{K},$$

where

$$\begin{aligned} K_1 &= \text{Sieverts' constant,} \\ K &= \text{equilibrium constant.} \end{aligned}$$

In view of the fact, however, that Sieverts' law involves the dissociation of the molecule into atoms, the absorption of hydrogen by iron may be represented by the reaction :



and the equilibrium constant of the reaction will then be given by :

$$K = \frac{(\text{FeH})^2}{(\text{Fe})^2(\text{H}_2)} = \frac{(\text{FeH})^2}{(p_{\text{H}_2})}$$

and

$$(\text{FeH}) = \sqrt{K} \sqrt{p_{\text{H}_2}} \quad (\text{Sieverts' law}),$$

where  $\sqrt{K} = \text{Sieverts' constant.}$

Since Sieverts' constant is known for the system iron-hydrogen (see Fig. 2), it is a simple matter to deduce from it the equilibrium constant of reaction (3).

$$\log K_p = - \frac{3,180}{T} - 3.4573,$$

and the variation of the free energy :

$$\Delta F_1 = + 14,542.4 + 15.802 T.$$

The absorption of hydrogen by iron is an endothermic phenomenon which probably takes place with the formation of a hydride of iron, with a heat of reaction equal to  $-14.5$  kg.cal. (gross figure) :



The heat of formation of FeH is therefore  $-7.2$  kg.cal. (approximately).

A comparison of the constant of thermal dissociation of hydrogen given by Langmuir's equation <sup>(11)</sup> :

$$\log K = \log \frac{(p_{\text{H}})^2}{(p_{\text{H}_2})} = - \frac{19,700}{T} + 4.89,$$

with the constant of the absorption of hydrogen by iron :

$$\log K_p = \log \frac{(\text{FeH})^2}{(p_{\text{H}_2})} = - \frac{3,180}{T} - 3.4573$$

shows that, above roughly  $1708^{\circ}\text{C.}$ , according to Langmuir's equation, atomic hydrogen will co-exist in the gas phase with the molten iron, without, however, being absorbed by the metal (see Fig. 3).

This point requires careful verification, since it is possible that the absorption of hydrogen by molten iron has not been studied very accurately at these high temperatures.

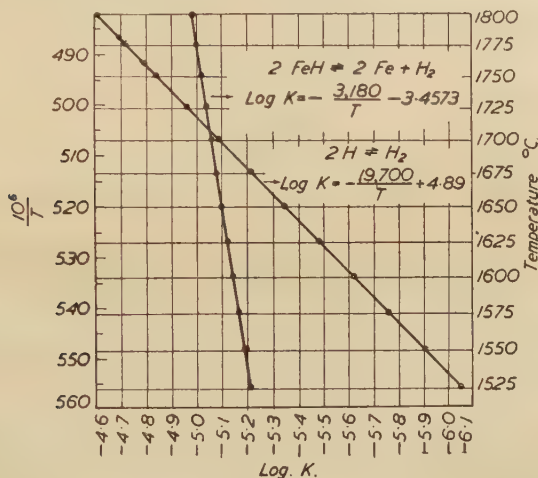


FIG. 3.—Equilibrium between Iron and Molecular and Atomic Hydrogen.

The other extreme case, *viz.*, the system oxygen/molten-iron, will now be examined.

The oxidation of molten iron by oxygen is governed by the reaction :



According to Chipman and Samarin <sup>(6)</sup> (*loc. cit.*, p. 8), who obtained good agreement with the results of Schenck <sup>(12)</sup> on the dissociation of FeO in molten iron, the equilibrium constant of this reaction is given by the equation :

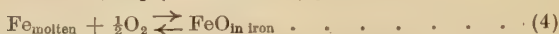
$$\log K = + \frac{2,960.87}{T} + 2.449166,$$

and the variation of free energy by :

$$\Delta F = -13,540 - 11.20 T.$$

On the other hand, the solubility of oxygen, or, rather, of FeO, in molten iron has been determined by Körber and Oelsen, <sup>(13)</sup> and their figures are equally valid (see Fig. 4).

By combining the two extreme cases that have just been discussed, *viz.*, the reactions :



with the thermal-dissociation reaction of water :



the following equation is derived :



and the constant :

$$K = \frac{(\text{FeO})(\text{FeH})^2}{(\text{Fe})^3(\text{H}_2\text{O})}$$

which defines the chemical equilibrium of the system formed by

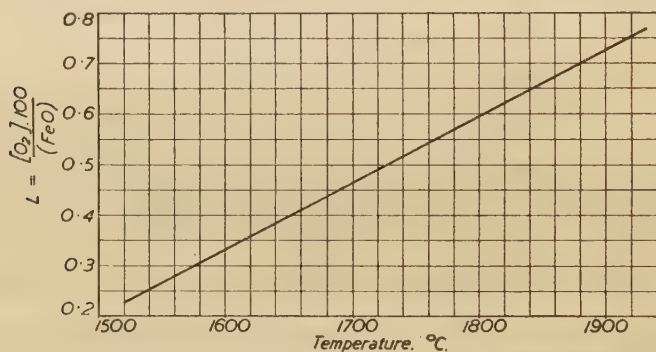


FIG. 4.—Solubility of Oxygen (*L*) in Iron.

water-vapour and molten iron. At the same time, the thermodynamic analysis enables the value of the equilibrium constant of equation (5) to be deduced from the foregoing arguments. It is :

$$\log K = - \frac{13,383.5}{T} + 2.04857,$$

while the variation of the free energy becomes :

$$\Delta F = + 61,202.4 - 9.368 T.$$

There are, however, no experimental data by which this equation can be verified, because researches of this kind have been carried out only for copper and nickel (Allen and Hewitt <sup>(8)</sup> and the author <sup>(9)</sup>). For this reason, a slightly different method must be adopted for calculating the co-existence of hydrogen and oxygen in iron in terms of known experimental data.



It has previously been stated that Chipman and Samarin had studied the reaction :



between  $1600^\circ$  and  $1770^\circ \text{C.}$ , and that they had experimentally determined the value of the ratio  $\text{H}_2\text{O}/\text{H}_2$  in the gas phase above the molten iron, as well as the corresponding percentage of  $\text{FeO}$  dissolved in the metal.

From this they deduced the equilibrium constant :

$$K = \frac{(\text{H}_2\text{O})}{(\text{H}_2)(\% \text{FeO})}$$

as :

$$\log K = + \frac{10,200}{T} - 5.50,$$

and the variation of the free energy as :

$$\Delta F = - 46,660 + 25.17 T.$$

In this investigation, the absorption of hydrogen by the metal was ignored.

However, by combining equations (5) and (6) it is possible to work out the figure for the simultaneous presence of hydrogen and oxygen, or, rather, for the oxide and hydride, absorbed by the metal.

It should be noted that the equilibrium constant of one of these equations has been determined directly by means of experimental data, while the other has been calculated from thermodynamic considerations, and also on known experimental and spectroscopic bases.

Thus the reactions :



$$\Delta F = - 61,202.4 + 9.368 T,$$

and :



$$\Delta F = - 46,660 + 25.17 T,$$

when combined, give :



with

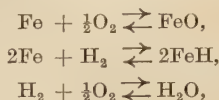
$$K = \frac{(\text{Fe})^4(\text{H}_2\text{O})^2}{(\text{FeO})^2(\text{FeH})^2(\text{H}_2)}$$

$$\Delta F = - 107,862.4 + 34.538 T \quad . \quad . \quad . \quad (7a)$$

and

$$\log K = + \frac{23,586.82}{T} - 7.5526 \quad . \quad . \quad . \quad (7b)$$

The thermodynamic verification of this equation with the help of the well-known reactions :



has led to this same equation (7b).

It is therefore equation (7) which best represents the mechanism of the reaction of water-vapour with molten iron, and enables the value of the ratio of the oxide to the hydride dissolved in the iron to be worked out from the experimental data previously published, since the only unknown quantity in this equation is the FeH concentration.

From Chipman's experimental results the author has calculated, for three different temperatures (1525°, 1600° and 1700° C.), the

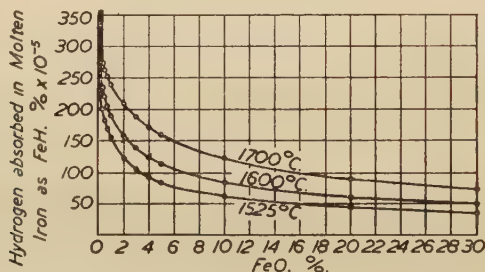


FIG. 5.—Co-existence of Oxygen (FeO) and Hydrogen (FeH) in Iron.

percentage of oxide in the iron in terms of the percentage of hydride ; the results are plotted in Fig. 5. It is interesting to note that these curves are identical in shape to those already obtained experimentally by Allen and Hewitt <sup>(8)</sup> and by the author <sup>(9)</sup> for copper and nickel, with this difference, however, that the hydride concentration is much higher for a given percentage of oxide.

Obviously these curves have chiefly a theoretical interest, because in actual practice the solubility of oxide of iron is much below the value indicated by the curves. When the limits of solubility of FeO in iron are exceeded, the surplus oxide FeO passes over into the slag, so that the oxide FeO is distributed between the slag and the metal in a ratio defined by the coefficient of distribution :

$$L = \frac{\text{FeO in the metal}}{\text{FeO in the slag}},$$

which is a function of the temperature.

An examination of the curves representing equation (7), how-

ever, shows that about 20% of FeO is necessary to eliminate the excess of hydrogen absorbed by the metal; further, practical experience demonstrates that the concentration of FeO in the slag is of this order.

The author wishes to tender his thanks to Monsieur Y. Dardel, Ingénieur des Arts et Manufactures, Engineer at the Dives Works of the Compagnie Générale d'Electro-Métallurgie, for his kind collaboration.

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## CORRESPONDENCE.

Dr. A. McCANCE (Member of Council, Glasgow) wrote that no one would dispute Monsieur Lepp's conclusions that in molten iron the simultaneous existence of hydrogen, iron oxide and water vapour could be supported on theoretical grounds.

Balanced reactions had the helpful characteristic that if a number of such reactions in a system were possible, and one was in equilibrium, then they were all in equilibrium.

Consequently, in molten iron, where it was admitted that iron oxide and hydrogen existed, the products of the interaction of these three substances would also co-exist at the same time.

Thus water vapour, iron hydride, atomic hydrogen and free oxygen were all constituents which were present in molten iron to some degree or another, depending on the concentration and temperature of the three original substances.

Whether Monsieur Lepp's calculations gave anything more than a qualitative answer to the amounts of these reactants present in iron was very doubtful.

The weakness in his chain of reasoning was the dissociation reaction for water vapour :



Known data for this referred only to the gaseous state, whereas accuracy demanded that the constants for this reaction when all three constituents were dissolved in iron should be used for Monsieur Lepp's purpose.

It might be that the heats of solution cancelled out, but until this was known with certainty there would always remain a doubt regarding any conclusions drawn from thermodynamical calculations.

Mr. G. PHRAGMÉN (Stockholm, Sweden) wrote that the equilibrium between hydrogen in a gas phase and in liquid steel might be represented by the equation :

$$\text{Log} \frac{(\% \text{H})^2}{\{\text{H}_2\}} = - \frac{3180}{T} - 3.46,$$

$\{\text{H}_2\}$  being the activity of hydrogen with pure hydrogen at atmospheric pressure as standard. The percentage of hydrogen in the iron should not be denoted by  $(\text{FeH})$ . The author had cited the investigations of Chipman and Samarin, according to which :

$$\text{Log} \frac{\{\text{H}_2\text{O}\}}{\{\text{H}_2\}(\% \text{FeO})} = \frac{10200}{T} - 5.50.$$

These two equations were (according to the writer) sufficient for calculating the hydrogen and oxygen contents of the liquid steel from the partial pressures of hydrogen and water in a gas phase at equilibrium with the steel, or the reverse.

By doubling the second equation and subtracting from it the first one, the following equation was obtained :

$$\text{Log} \frac{\{\text{H}_2\text{O}\}^2}{(\%\text{FeO})^2(\%\text{H})^2\{\text{H}_2\}} = \frac{23580}{T} - 7.54.$$

He could not, however, accept the author's statement that this was the equation " which best represents the mechanism of the reaction of water-vapour with molten iron." The last rather complicated equation could not contain anything more than the convenient equations from which it had been derived. He wished also to warn against the confusion of mol fraction with percentage which might arise from the notation (FeO), as used by the author.

In Fig. 4 the solubility of oxygen in liquid iron was given as a straight-line function of the temperature. If the axes of oxygen content and temperature were interchanged it was obvious that the line in question was an ordinary solubility curve in a phase diagram. As the author had used to a great extent the equations of Chipman and Samarin, he might also have used the following equation for the oxygen content :

$$\text{Log} \frac{(\%\text{FeO})}{\{\text{FeO}\}} = -\frac{26300}{4.57T} + \frac{14.64}{4.57} = -\frac{5750}{T} + 3.20.$$

At saturation with the oxide phase one might assume  $\{\text{FeO}\} = 1$ .

The liquid iron, when saturated with hydrogen at 1600° C. and atmospheric pressure, contained 0.0026% of hydrogen. It might be asked how much the hydrogen content would be when the iron was saturated with FeO at the same temperature, the total pressure of hydrogen and water being one atmosphere. From the equations given here it was found that the partial pressure of hydrogen was 0.46 atm. and that of the water 0.54 atm. Hence, the hydrogen content of the liquid iron was as high as 0.0018%.

In Fig. 5 the author represented the percentage of hydrogen (not of FeH) in the liquid iron as a function of its oxygen content at different temperatures. He then stated that " about 20% of FeO is necessary to eliminate the excess of hydrogen absorbed." It was difficult to understand why just the value 20% of FeO in the liquid iron had been chosen, all values above 1.5% being unrealisable. But it was even more necessary to explain why the content 20% of FeO *in the slag* should have any specific importance.

The author's reply had not been received at the time of going to press.





# METHOD OF SCLERO-GRATING EMPLOYED FOR THE STUDY OF GRAIN BOUNDARIES AND OF NITRIDED CASES; GRAIN STRUCTURES REVEALED BY CUTTING.\*

By BO O. W. L. LJUNGGREN (METALLOGRAFISKA INSTITUTET, STOCKHOLM).

(Figs. 19 to 116 = Plates XXII. to XXXIX.)

## ABSTRACT.

Use has been made of the method of Benedicks and Mets for the detailed study of relative hardness, namely, ruling a fine grating on a polished metal surface. This procedure—designated here as “sclero-grating”—has been made highly sensitive, mainly by making the point-bearing part very light, with great lateral stability. Thus, the hardness difference between adjacent grains clearly reveals the grain structure of a metal—as in grain field etching. By the use of very low pressure and a small ruling distance it is possible to detect cold-working resulting from grinding.

On iron as well as on aluminium, after annealing in nitrogen, grain boundaries were observed for which the sclero-grating method indicated a slightly greater hardness than that of the ground-mass, without any separated phase being visible there under the microscope. This may be interpreted as a molecular enrichment of nitride in the boundaries in support of the theory of Benedicks and Löfquist.

It has been shown that in order to reveal small hardness differences a strictly geometrical shape of the ruling point is by no means necessary; particularly high sensitivity is frequently attained through the action of a “secondary point.”

Good harmony has been found to exist between the configuration of the ruling point and the rulings obtained when examined at a high magnification.

The sclero-grating method has also been employed for the detailed study of the individual hardness of the micro-constituents of a nitrided case. Consideration of the results obtained seems to provide a reasonable explanation of the behaviour of the total-hardness curve of a nitrided steel.

In connection with the sclero-grating experiments, some tests have been made on the cutting of soft metals with a sharp knife (a laterally extended point). When using a sufficiently large free-cutting angle the grain structure was beautifully developed, and also a remarkable coarse structure which may be considered to be a characteristic feature of “pure” metals.

During the work, a few other observations were made. Thus, on prolonged heating of commercial aluminium, the compound  $\text{Al}_3\text{Fe}$  was found to protrude above the free surface of the specimen; in a nitrided surface, a certain crack formation was observed and is explained as being due to blisters caused by local high pressure.

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\* Report on a research carried out with the aid of a grant from the Andrew Carnegie Research Fund, received July 20, 1939.

## I.—MICRO-SCLEROMETRIC RESEARCHES ON THE GRAIN BOUNDARIES OF SOME METALS.

A.—*Introductory ; Method Employed.*(1) *Opening Considerations.*

The aim of the work has been to investigate whether a molecular concentration, or adsorption, in the grain boundaries, assumed by Benedicks and Löfquist<sup>(1)</sup> to be a hindrance to grain growth, might give rise there to an increase of hardness which could be demonstrated by the micro-sclerometric method. In any case, only an extremely thin molecular layer might be expected, and hence it is obvious *a priori* that very great demands will be made on the sensitivity of the method.

For this purpose a sclerometric method, which was first employed by Benedicks and Mets<sup>(2)</sup> was considered the most appropriate. This method consists in ruling a grating—which might show possible hardness variations—on a polished even surface, using a sharp hard point. The method may thus be described as a micro-sclerometric grating method, but for the sake of brevity the designation *sclero-grating method* will be used.

It is thus akin to the sclerometric procedures of earlier scientists, such as the rather refined work produced by Bierbaum,<sup>(3,4)</sup> though in his case only single lines were made and measured. The fact that here there is a great number of ruled equidistant lines permits of local variations in hardness to be observed more sharply.

The procedure concerned—applicable to numerous metallographic problems—has been progressively improved to a not inconsiderable extent. It has been employed here also for the detailed study of the micro-constituents of nitrided cases. In connection with the ruling, work has been devoted to the cutting of soft metals, especially lead.

(2) *Historical Survey of Micro-sclerometry.*

The first sclerometer was constructed in 1833 by A. Seebeck, who used it for mineralogical investigations. The cutting point was made of steel. R. Franz (1850) used also a diamond point. T. Turner (1886) introduced the sclerometer as a metallographical appliance, but it was only after the improvements made by A. Martens (1890) that it gained widespread employment and importance.

An historical survey of all scratching methods that have been described, right back to the time of Réaumur, who endeavoured to use points of different materials (glass, topaz, diamond) for scratching a given specimen, until the latest improvements made, is to be found in "Gmelin's Handbuch der anorganischen Chemie."<sup>(5)</sup> Historical surveys have likewise been given by Goerens and

Mailänder,<sup>(6)</sup> by Wretblad<sup>(7)</sup> and by Francke.<sup>(8)</sup> Hence the present author has considered it advisable to give only a survey of the work of Bierbaum and of Benedicks and Mets, which is fundamental for this paper, and also interesting points from a paper by Richter.<sup>(9)</sup>

Bierbaum, whose detailed experiments constitute a corner stone in respect of newer scratching methods, sought particularly to obtain the relative hardness of the different grains of a bearing metal. As methods used earlier were found impracticable, Bierbaum constructed a sclerometer, called by him a "micro-character," equipped with a microscope. This apparatus enabled him to determine the hardness differences in a cut made in that metal. The lowest pressures used on the point were 9 g. for hard objects and 3 g. for soft ones.

The requirements which, according to Bierbaum, are to be fulfilled by the cutting point may be said to be as follows :

(1) The cutting point must have a geometrically definite form and must be ground with extreme precision—so as to slide easily on the surface even with considerable vertical pressure.

(2) It must be flexible and possess a small mass, so as to respond to any successive elevations on the surface, thus exercising a constant pressure.

(3) The cutting point must be moved over the test surface at a uniform rate, slowly enough for no additional indentation to occur when stopping on the softest material.

Diamond, on account of its hardness, was first utilised, but proved very difficult to grind. It was found that artificial leucosapphire (molten  $\text{Al}_2\text{O}_3$ ) was easy to grind and possessed satisfactory hardness and homogeneity.

Concerning the shape of the point, Bierbaum considered it impossible to grind a conical point that would be quite geometrical, so that with the highest magnification used in the microscope it would prove to consist of a single sharp peak. He finally arrived at a well-defined form, namely, the solid angle of a cube, which was adjusted so that the corresponding diagonal of the cube was normal to the surface of the object, one of the edges advancing in the plane of motion.

A good idea of the applicability of the "micro-character" may be obtained from some recent American papers.<sup>(10)</sup>

A special hardness test has been carried out by Richter<sup>(9)</sup> on thin slices of nickel (from 1  $\mu$  in thickness). The cutting mechanism, used throughout at very low pressures, down to 0.01 g., consisted of a balance in the one end of which a cutting point was fixed. Having first used a 90° diamond point, Richter found it wore heavily and he increased the conical angle to 120°.

As for the method of Benedicks and Mets,<sup>(2)</sup> the sharpness of observation already mentioned may result from details in the

configuration of the point, as illustrated by Fig. 1. Here *A* designates a portion of lower hardness. If only a single scratch is made the differences in the width of the scratch will be but slight (Fig. 1 (0)). If, on the other hand, a large number of scratches are made at short intervals, the relative change of width in the space between is much easier to observe than the changes in width of the individual scratches, this irrespective of the shape of the point (Fig. 1 (1)).

In the diagram, (2), (3) and (4) may be considered to be special cases. (2) makes clear how a point which is provided with a small lateral projection may react when passing over a softer place. At a given pressure, which may conveniently be designated as critical, the projection makes a subsidiary scratch on the soft portions but no such impression on the harder ones. In the present work this case has many times been found important for the establishment

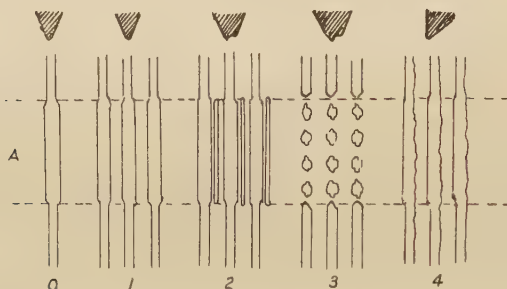


FIG. 1.—Different Kinds of Point Action (Benedicks and Mets).

of differences in hardness, evidenced only by means of this secondary action.

If the point be blunt or the pressure low, case (3) may occur, implying that a broken scratch is obtained on the portion *A*, in this case harder.

If, finally, the point is of such a shape that it has an actual cutting effect, the different portions of slightly dissimilar hardness may be detected by the varying appearance of the edge of the scratch (Fig. 1 (4)).

### (3) Apparatus.

The machine used for the cutting was the automatic linear dividing machine obtained from the Société Genèveise d'Instruments de Physique (Type No. 0016, Series No. 20). The maximum length of the cuts was about 30 mm. and the shortest interval between them, or "the ruling distance," *l*, was originally 5  $\mu$ .

The construction of the cutting device, as already used in the



previous work by Benedicks and Mets, was in principle designed in the following way (see Fig. 2, where  $a$  is a horizontal and  $a'$  a vertical projection). Between two steel points,  $A_1$ ,  $A_2$ , a balance  $B$  is pivoted. At one side is fixed the cutting head,  $C$  or  $C'$ , provided with a graduated disc (angle  $\alpha$ ), and also a movable weight  $D$ , which provides the requisite pressure on the point.  $E$  is a counterweight.  $F$ ,  $F'$  is a damping device comprising a perforated disc immersed in oil; the damping was necessary in order to obtain on the object  $H'$  an even continuous scratch which displayed only actual hardness differences.

The point could be rotated in a vertical plane parallel with the line of the scratch; the setting was given by the angle  $\beta$ . When scratching, the points  $A_1$ ,  $A_2$  move along the lower part of a segment of a circle. The situation of this may be judged from Fig. 19, in which  $A_2$  is marked  $A$ .

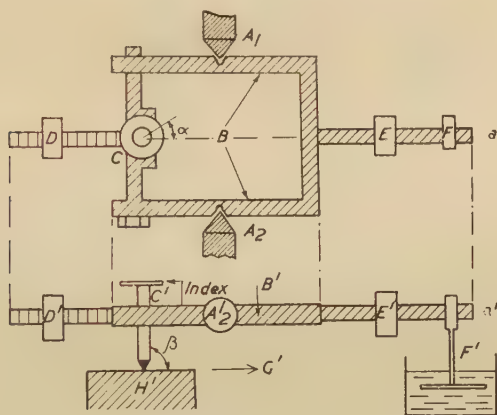


FIG. 2.—Earlier Ruling Mechanism.

When ruling on glass, as was necessary for adjustment, very fine scratches were obtained. On turning over to metal the operation was not so good, inasmuch as disturbances and a certain periodicity of the machine were plainly apparent on the object. In view of this some preliminary improvements had to be made :

(1) The points  $A_1$  and  $A_2$  (Fig. 2), as well as the corresponding bearing surfaces of the balance, were carefully ground and polished, this being done to decrease the friction.

(2) The centre of gravity of the balance  $B$  was lowered so as to be situated immediately below the bearing line, thus ensuring a stable equilibrium, which had not been the case previously.

(3) The ruling speed was lowered from 4 mm. to 2.5 mm. per sec.

(4) The oil damping was dispensed with, as it caused variations in the pressure. In view of the lowering of the ruling speed, damping was no longer necessary.

In order that at the points  $A_1$ ,  $A_2$  there should be a small amount of friction, also a little play, a few different oils were tried. It was found—naturally enough—that for a given amount of friction, determined by the small additional weight  $D$  causing a movement of the balance, the least play was obtained when a thicker oil was used.

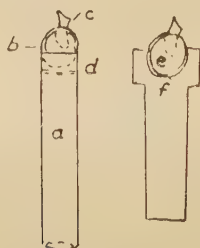


FIG. 3.—Fastening of Diamond Splinter (Benedicks and Mets).

That the ruling speed should not be too high was shown experimentally. Under otherwise similar conditions, a speed of 2.5 mm. per sec. produced discontinuity in the lines, whereas with a speed of 1.0 mm. per sec. the lines were much more uniform.

It was an inconvenience that the point when not ruling, as indicated above, followed an arc of a circle, as this caused pressure that was not constant along the whole scratch, but was greatest at the middle. The modifications providing for constant pressure as well as some other improvements will be described in connection with the progress of the work.

#### (4) *Ruling Points.*

The first ruling points used were sharp diamond splinters, which were mounted in the following way: A brass rod,  $a$  (Fig. 3), was rounded off at one end and provided with a slit  $b$ , in which a selected diamond splinter  $c$  could be inserted and fixed with the aid of pliers. The slit having been soldered up (tin-lead solder), the rod was cut at the constriction  $d$  and the little piece rounded off, likewise on the lower side. The little sphere so formed was placed in the excavated end of a brass rod  $e$ , permitting it to be adjusted at a convenient position, and then soldered. The rod  $e$  fitted in a

holder free to turn in the ruling device, and for adjustment the holder had a graduated dial (*cf.* Fig. 2, *C*, *C'*). Later on, each point was provided with such a dial.

By examinations under the microscope efforts were made to arrive at a convenient ruling position for the point; thereby the angles  $\alpha$  and  $\beta$  (Fig. 2) were determined.

The action of such a diamond point, however, is generally dependent on accidental circumstances. Hence, experiments were made in the use of ruling points of geometrically different shapes, as Bierbaum had done.<sup>(3,4)</sup> In the first place a conical point was used, being simpler to grind and easily permitting variation of the (smallest) angle between the ruling direction and the angle of the cone (angle  $d$  in Fig. 4). The top angles of the cone varied between  $60^\circ$  and  $150^\circ$ .

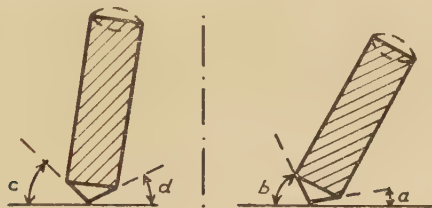


FIG. 4.—Diagram Defining Angles  $a$ ,  $b$ ,  $c$  and  $d$ . The left half of the diagram is a side elevation of the ruling point moving from left to right. The right half shows the ruling point as viewed moving from the eye.

As it was considered still more important to be able easily to vary the side angle  $a$  shown in Fig. 4, by which an increase in sensitivity might be sought for small hardness differences, the following procedure was adopted: A cylinder ( $3 \times 5$  mm.) of the hard metal "Seco" (furnished by Fagersta Bruks A.B.) was ground off so as to give a cone of  $122^\circ$ , the axis of which formed an angle of  $15^\circ$  with that of the cylinder. The point thus shaped was fastened in the cutting head in a small tube, which formed an angle of  $15^\circ$  against the normal of the surface of the specimen; this position was determined by angle  $\alpha$  (Fig. 2). The angles  $a$ , ( $b$ ),  $c$  (and  $d$ ), as defined in Fig. 4, could be varied by altering angle  $\alpha$  between  $58^\circ$  and  $0^\circ$ . The determination for  $\beta = 90^\circ$  was obtained by certain curves reproduced in Fig. 5.\*

A good deal of work was done in these experiments aiming at determining systematically how far the different angles of inclination might affect the sensitivity obtainable with a given point. It was found, however, that, with the degree of precision attained with

\* The author is much indebted to Mr. P. Sederholm, engineer assistant, for his help in this matter.

the grinding here, the character of the rulings was more dependent on the local variations in the surface than on the angle  $\alpha$  or others. It was essential that the specimen should be very firmly held (by fixing in a small steel vice).

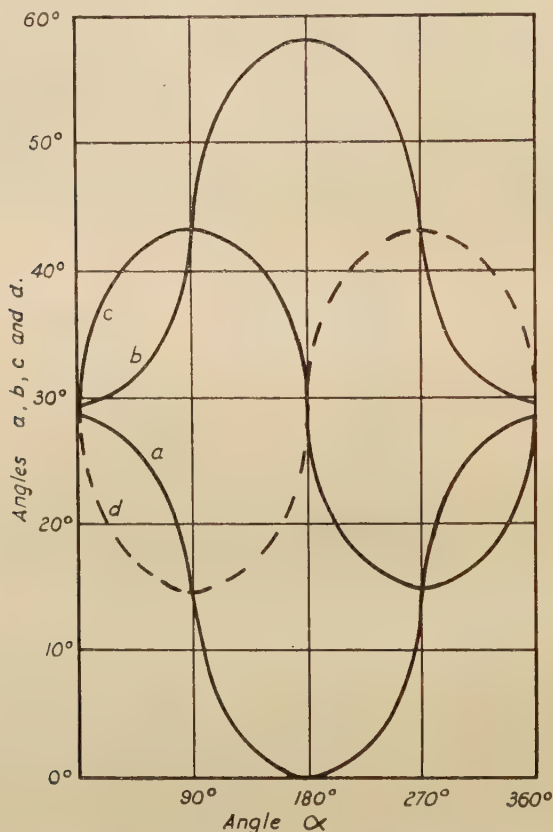


FIG. 5.—Curves Determining Angles  $a$ ,  $b$ ,  $c$  and  $d$  as functions of  $\alpha$ .

Different materials for points were tried out; besides diamond and the hard metal Seco, use was made of quenched, slightly-tempered steel, quartz and calcedony. The Seco metal has proved to be a rather good material for the purpose, possessing good hardness and wearing properties.

The points were ground in a small watchmaker's lathe, using a copper disc coated with levigated diamond powders of different grades of fineness. The greatest difficulty was found in getting the lathe sufficiently free from vibration during the final polishing.

It is probably for a similar reason that Bierbaum chose the cubic corner, although it was less symmetrical than a conical point.\*

During the progress of the work it was found that it was extremely difficult to produce a point that was geometrically sharply defined at the high magnification that was necessary here (1500 diameters). The extreme end of the point always turned out to be less well-defined, possessing a certain bluntness, or at best consisting of several small peaks, situated nearly in the same plane.

It was eventually found, however, that a well-defined point is by no means necessary for the *qualitative detection* of hardness differences; as shown by Benedicks and Mets, a point possessing lateral protuberances frequently gave a very high sensitivity (cf. p. 344 P and Fig. 1 (2)). (If the *quantitative determination* of hardness is required, a well-defined point might, of course, be desirable.)

Efforts were consequently made to obtain points possessing one or more lateral protuberances, lying on a level not appreciably different from that of the main peak. Thus, a sharp straight edge (angle  $60^\circ$ ) was ground on a small Seco cylinder, forming an angle slightly less than  $90^\circ$  with the axis of the cylinder. This edge was adjusted at right angles to the ruling direction. This point proved to give considerable sensitivity, owing to the existence of unevennesses in the edge. It was, however, rather brittle, so that no good reproducibility could be obtained. Preference, therefore, was given to the use of sharp diamond splinters.

Useful information regarding the action of a point was obtained by making a microscopical investigation of one diamond point and comparing it with the appearance of the rulings made, combined with the locating of the positions of the dominant peaks (cf. p. 365 P).

Later on some rulings were made with  $90^\circ$  conical diamond cones, ground and delivered by the Diamant-Werkzeugfabrik Haga, Berlin; their tips, however, could not be said to be sufficiently well defined for the present purpose.

### B.—Sclero-grating Tests on Iron Annealed in Air.

#### (1) *Analyses of the Test Materials Used.*

The analyses of the test materials used are given in Table I.

TABLE I.—*Analyses of the Test Materials Used.*

No.	Charge No.	Carbon. %.	Silicon. %.	Manganese. %.	Phosphorus. %.	Sulphur. %.	Oxygen. %.	Aluminium. %.	Chromium. %.	Vanadium. %.
1	X2265	0.62	...	0.35	0.022	0.009	...	...*	0.19	0.03
2	E6641	0.04	2.56	0.19	0.024	0.006	...	...*	...	...
3	B1320	0.04	...	0.17	0.026	0.011	...	0.02	...	...
4	K N571	0.05	0.01	0.13	0.006	0.022	0.0073	...	...	...
5	R24155	0.04	Trace	0.45	0.026	0.009	0.0103	...	...	...

\* Made with the addition of aluminium.

\* When grinding the surfaces of such a corner, the grinding tool works along a whole surface, while when grinding the cones, the tool works only along a line.



## (2) Preliminary Tests.

Using the apparatus as slightly improved after the very first experiments, a grating was made on iron No. 1. It was a slightly hypo-eutectoid electric steel.

The grating tests were made with four different vertical positions of the ruling point (diamond); for each of the four positions five different pressures were used, with and without oil on the surface ruled. The following observations were made :

(1) A weak *grain structure appeared*—unexpectedly enough—being visible to the naked eye, with a certain oblique illumination, on the portions ruled, especially when using rather high pressure. Under the microscope, however, no grain structure could be observed (*see below*).

(2) A periodic irregularity in the grating appeared, especially with a rather small load. This irregularity, evidently due to the running of the machine, decreased when the ruling speed was diminished.

(3) The presence of oil did not sensibly affect the ruling.

(4) No greater hardness in the grain boundaries could be observed.

The material used, however, was too heterogeneous, containing much pearlite, which caused a disturbance of the lines, so that any hardness difference was difficult to observe.

Trials were then made with two irons with 0.04% of carbon, free from pearlite and relatively free from inclusions (Nos. 2 and 3). No. 2, a silicon alloy, gave a rather unsatisfactory surface on polishing.

On both these irons a comparatively large portion was ruled with the diamond splinter already employed. The ruling distance  $l$  was 10  $\mu$ .

After ruling, the silicon iron had a rather irregular appearance, though at some points it gave a vague grain structure (Fig. 20). At this low magnification (10 diameters), the lines themselves can hardly be seen, so that the sclero-grating gives the same impression as a photograph. Hence, in the following the term "sclerograph" will be used when the rulings are so close as to give a structural impression.

The grain structure appeared very clearly on No. 3 (Fig. 21)—to the naked eye as well as under the microscope. The angle of setting was slightly different for the three portions ruled.

The grain structure thus obtained by purely mechanical means was well supported by the chemical etching structure, as shown by Fig. 22 (etched with 1% nitric acid in ethyl alcohol). The dark portion is that which was ruled (Fig. 21).

Thus, the preliminary experiments with the sclero-grating method show that *the grain structure does appear more or less plainly*

for different materials, at least for a given configuration and pressure of the ruling point.

This result may be said to be a further development of that obtained by Benedicks and Mets,<sup>(2)</sup> showing very great sensitivity of the grating results for small local differences (a "physical etching").

### (3) *Change-over to a Spring-Mounted Point.*

It had been found, however, that the ruling point, being solidly attached to the ruling mechanism, was too much affected by the unevenness of the surface ruled and by irregularity in the running of the machine. Hence the original method of applying to the

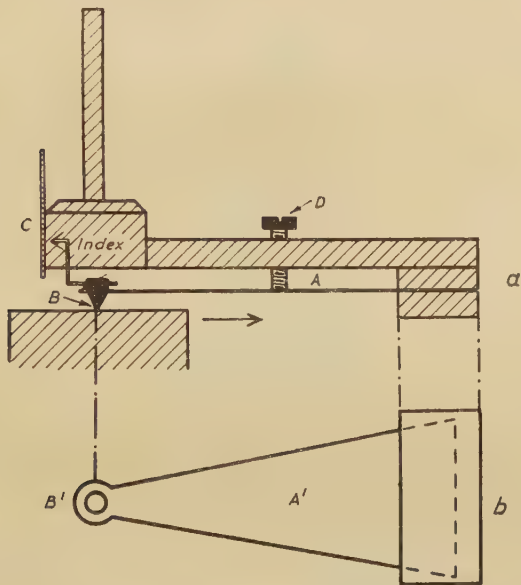


FIG. 6.—Ruling Head with an Elongated Spring.

point the required pressure by means of weights was abandoned. Pressure was obtained instead by means of a spring, as used by Bierbaum, which gives a ruling device moving freely.

On account of this, a new ruling head was made (Fig. 6), corresponding to *C, C'* in Fig. 2. Here a flexible spring strip (*A, A'*) in the form of an isosceles triangle and made of thin phosphor-bronze sheet, was fixed with solid screws. The top of the triangle carried the ruling head (*B, B'*). *C* is a graduated scale for reading the deflection of the spring to show its pressure, being provided with an index fixed on the spring. The weight of the point holder was reduced as far as possible.

It having been established that the pressure obtained was proportional to the elevation of the point, the pressure could be varied by altering the position of the ruling head or of the specimen. A screw *D* permitted the spring to be tightened more or less.

This new system had the advantage that the play at the points  $A_1, A_2$  (Fig. 2) entirely disappeared.

Preliminary grating tests showed, as was expected, that the irregularities in the machine due to disturbances were considerably lessened.

At the same time, however, the resistance of the point to lateral movement and to tilting was not satisfactory. The remedy was as follows: The point-bearing part, *A*, Fig. 7, was made as rigid as

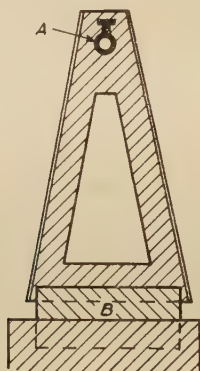


FIG. 7.—Rigid Point-Bearing Part with a Narrow Spring.

possible and the spring was restricted to a narrow strip, *B*. This considerably increased the lateral stability.

Rigidity was obtained by using an aluminium triangle cut out in the middle and with the edges bent up.

#### (4) *Grating Tests using the Spring-Mounted Point.*

Following the introduction of these improvements to the point holder, rather satisfactory ruling results were obtained. This is illustrated by Fig. 23. Iron No. 3 was ruled with a diamond splinter, using a pressure of 1.0 g. and a distance  $l = 10 \mu$ . The illustration shows where the point had passed over a few large non-metallic inclusions considerably harder than the iron. Differences in the hardness of the inclusions are plainly evident.

It was found—as had not been observed earlier—that portions with the greater width of ruling—that is, the softer ones—had a lighter colour than the harder parts. This proved the areas to contain two different phases, though the nature of these could not

be ascertained; it may be supposed that the slightly softer phase was richer in sulphide, the harder one richer in silicate.

An increase of hardness in the grain boundaries could not be observed, however.

Two further similar materials, irons Nos. 4 and 5, were then tested. They were annealed for approximately 5 hr. at about  $850^{\circ}\text{C}$ ., slightly below the  $\gamma$  transformation point, and were then slowly cooled. After the annealing, the cementite in No. 4 had sensibly the same appearance as before, *i.e.*, it occurred as lumps in the interior of the grains. In No. 5, on the other hand, typical precipitations of cementite occurred in the grain boundaries (Fig. 24). Accordingly it could be expected that a molecular enrichment might occur in the grain boundaries where no precipitation of cementite was discernible under the microscope. Hence, this iron seemed to constitute a suitable material for investigation and was subsequently employed almost exclusively. Its grain structure as revealed by etching is reproduced in Fig. 25.

After only a few tests success was achieved in developing this grain structure by the grating method (Fig. 26). The most appropriate distance between the lines was found to be  $l = 5\ \mu$ . As in earlier tests, the structure appeared better with fairly strong pressure.

The fact that in Fig. 26 this structure does not stand out so well in the upper part is due first to the pressure there having been lower (approximately 0.7 g.) than in the lower part (approximately 1.00 g.), on account of the circular motion of the ruling device already referred to (*see* p. 346 P).

The great clearness of the grain structures obtained seems to be accentuated by the fact that the boundaries at many places were lighter than the grains on both sides, *i.e.*, the rulings there were narrower. *Thus, along the grain boundary the hardness was greater than in the bulk of the specimen.* This may be illustrated at a higher magnification by Fig. 27. The narrow light bands visible here and there could possibly be supposed to correspond to a molecular enrichment of cementite, though it is more probable that the greater hardness depended only on a local precipitation of cementite. In order to decide this question, the specimen was etched with alkaline picric acid, which is known to tinge cementite black. After etching, the same part illustrated in Fig. 27 is shown in Fig. 28. A few light bands seen in Fig. 27 are now plainly visible as dark areas, proving the presence of cementite. With some other light bands it was not possible to decide definitely whether precipitation (blackening) had taken place or not.

Cementite, as is well known, however, frequently does not blacken when very thin. Thus, it may be possible that even in the light bands where no blackening has occurred there might be a thin precipitation of cementite.

These observations, however, did not exclude the possibility

that the hardness occurring along certain boundaries might be due to molecular enrichment. It was therefore deemed necessary to improve the method still more.

(5) *Final Improvement of the Ruling Apparatus.*

In spite of the measures taken it was found that the point was not quite stable laterally; it was deflected considerably by some harder inclusions (cementite, darkened by etching) at a wide angle to the ruling direction, though when it had passed it quickly returned to the original direction.

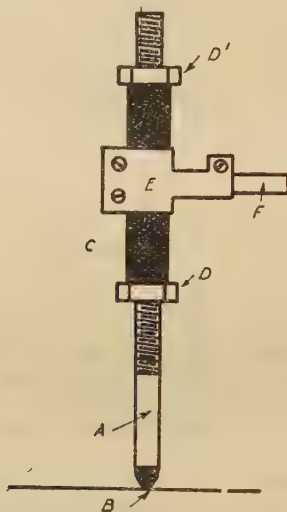


FIG. 8.—Support giving Constant Pressure.

Hence, some final alterations to the ruling device were made in order to gain further lateral stability and at the same time to ensure a constant pressure of the point for the portion ruled.

A constant pressure was achieved by the introduction of a support fixed to the ruling device. When this had been lowered to give the desired pressure, the support rested on a surface parallel with that ruled.

The support consisted of a brass rod *A*, Fig. 8, the lower part of which carried a piece of ivory *B*. *A* had a screw thread and was free to move in the tube *C*. Raising and lowering were effected by means of the nuts *D* and *D'*. The support was fixed to the ruling device by means of the holder *E* and the upright *F*.

By allowing the ivory to glide against a glass plane on the working table and also by the application of oil the movement became quite free from vibration.



This support, while ensuring a constant pressure, limited the ruling length available, but this was in any case sufficient.

The lateral stability was improved in the following manner: The narrow spring strips were replaced by two separate flat steel

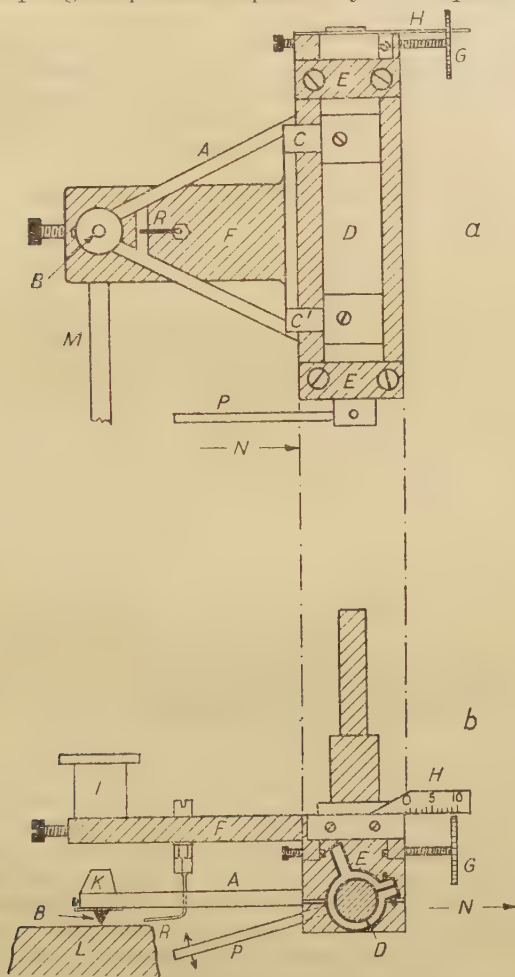


FIG. 9.—Ruling Device after Final Improvements. (a) Plan. (b) Elevation. Two-thirds natural size.

springs ( $0.045 \times 2.5 \times 3.5$  mm.)  $C$  and  $C'$ , Fig. 9, in which  $a$  shows the ruling head from below and  $b$  a side view. Each of these springs was soldered on to a corner of a triangle with the middle cut out ( $A$ ), this time made of thin sheet brass. The triangle was

given a nearly equilateral form, thus providing the highest stability possible (*cf.* R. Strömberg <sup>(11)</sup>). Its apex, strengthened by a cross-piece, carried the ruling point *B*. The weight of the ruling device (triangle, point holder and springs) after these modifications amounted to only 2.5 g.

In order to vary the pressure easily the springs were fixed in a holder cylinder *D*, which could rotate in two tubes *E*, *E'* attached to the solid frame of the cutting head. On rotating the cylinder by the arm *P* the tension on the springs was varied, and was measured by means of the screw *G* and the scale *H*.



FIG. 10.—Calibration Curve for Pressure  $p$  as a function of the adjustment  $\phi$ .  $\phi$  = scale divisions of screw.

The small springs being rather delicate and liable to damage in manipulation, the solid part of the cutting head was provided with a conical casing *I* which could be lowered so as to fit on the conical tube *K*, in which the point was fixed. This casing could be fastened to *K* by a small screw, not visible in the diagram. By this means the motion of the instrument could be arrested.

*R* is a limiting device, consisting of a brass wire so bent as not to interfere with the free motion of the triangle *A* when the point is ruling. *L* is the specimen to be ruled (fixed in a vice), and *M* is the arm on which the above support is fixed. The arrow *N* shows the direction of ruling.

The drawing (Fig. 9) is supplemented by a photograph of the ruling device viewed sideways from below (Fig. 29); the placing of the support can be seen.

Thanks to the improved adjustment facilities provided by the

fine-pitched screw ( $G$ , Fig. 9), the pressure could be determined to within 0.01 g.

The calibration curve used is given in Fig. 10. The small deviations to be seen are due to a slight periodicity of the screw.

(6) *Sclero-gratings Obtained with the Final Apparatus.*

On subsequent rulings the point displayed very good stability even when passing over hard enclosures; the ruling distance  $l$  was fairly constant even at very low pressures.

This is evidenced to some extent by Fig. 30. Here  $l = 5 \mu$ , which was the lowest ruling distance of the dividing machine. The pressure was 0.20 g. The rulings, about  $0.5 \mu$  in width, were made with a  $120^\circ$  cone of Seco metal on iron No. 5. It will be seen that, despite the low pressure, the ruling distance is fairly constant, which had not been the case earlier. No deflection of the point is observable.

The ruling results obtained were so regular that it appeared desirable to be able further to diminish the ruling distance  $l$ , which according to the above might increase the sensitivity still more.

This was achieved by substituting for the single pawl, which allowed a smallest feed distance of  $5 \mu$ , a set of five pawls, the lengths of which were so adjusted that the distance between two teeth on the rigid wheel of the machine was now divided into approximately five equal parts. This enabled a smallest ruling distance  $l$  of about  $1 \mu$  to be obtained. (Because of a little lateral play of the pawls, the distance  $l$  varied slightly.)

Using a diamond splinter and ruling distance  $l = 2 \mu$ , a very clear difference of hardness between adjacent grains was obtained (iron No. 5,  $p = 0.20$  g.), as may be seen in Fig. 31.

There appeared to be no sensible increase of hardness in the actual boundaries between the grains.

The same point at a pressure of 0.08 g. displayed a very great sensitivity for harder phases. In Fig. 32 the point has just passed over some rather large cementite enclosures ( $l = 6 \mu$ ). The width of the rulings is only about  $0.5 \mu$  for the main mass and only about  $0.2 \mu$  on the cementite.

When the pressure was still further decreased, the point turned out to be strongly affected by disturbances, and attempts were made to reduce this by means of some liquid on the ruling surface. As had been found by Bierbaum, a high-quality watch oil (neatsfoot oil) proved rather suitable, possessing a sufficient viscosity and apparently not attacking the surface.

The disturbances were practically eliminated, but the effective pressure was increased (Fig. 33). Here iron No. 5 has been ruled with a diamond point ( $l = \text{about } 1 \mu$ ;  $p = 0.05$  g.) both with oil (left) and without oil (right). On the right-hand side the point is seen to be unaffected by disturbances. The width of the rulings here is greater than elsewhere. This must be caused by a pressure

increase due to capillary attraction between the oil and the point. It was actually established by a separate test that the increase in pressure on the point, caused by the amount of oil, was raised 0.07 g., and this corresponds to the increase in width observed.

(7) *Tests with Blunted Points and Different Point Materials.*

As ruling with points as used above did not reveal any hardness differences in the boundaries, the question arose whether a blunted point might not give greater sensitivity.

Points, deliberately blunted spherically, of different materials (such as calcedony, quartz) quickly showed that nothing was to be gained with such points. Any possible increase in sensitivity was more than counterbalanced by greater difficulty in observing the rulings, on account of their rounded and uniform shape. In addition, there was the small depth of the impression.

Concerning *different materials*, it was deemed of interest to see how a point of *hardened, slightly tempered steel* would work, in spite of the wear to be anticipated. The width of the rulings proved to be *much more variable* (Fig. 34) than in any earlier rulings. Contrary to what had been observed before, *distinct secondary lines* appeared here and there. These observations indicate that the material ruled clogs the steel point on account of adhesion. Some *seizing* may be said to occur.

It was found that clogging occurred even when the ruling was done in oil.

The secondary lines showed variations in width closely following those of the main lines alongside. Hence the distance of the secondary peak from the main one may be considered to be extremely small. The sensitivity of the secondary lines to hardness variations seems to be much greater than that of the main lines.

Two kinds of hardness variation occur :

(1) *It is obvious that some inclusions, probably rich in MnO, are surrounded by a harder metal.* This may be observed on the inclusion slightly above the middle of Fig. 34, where two adjacent lines are even entirely broken. This is not due, say, to a hollow near the inclusion, as is proved by small sharp details in the same plane as the specimen.

It may be objected that, as the ruling point here consisted of steel, to which the similar material iron must have a definite adhesion, any decrease—or disappearance—of the width should not be interpreted so simply as when the ruling point is of diamond. Anyhow, the quenched-steel point possesses a considerably greater hardness than the ground-mass, and it would be rather arbitrary if lines obtained with a steel point were not to be considered as similar, in respect to hardness, to lines obtained by using ordinary point materials.

On the contrary, it seems quite reasonable that a steel point should *actually show a greater sensitivity for small variations in*



*hardness properties* than a point consisting of an entirely foreign material.

(2) It is, further, obvious that in a large grain, visible on account of the strongly oblique illumination in the right-hand part of the illustration, there are considerable hardness variations. These seem throughout to indicate that the part of the grain situated nearest to the grain boundary visible *is considerably harder than the portion of the grain further in.*

This greater hardness of the grain in proximity to the boundary, however, is distributed over a much greater distance from the boundary than one might expect from a molecular enrichment.

While earlier a considerable difference in ruling hardness had been observed in different grains of constant hardness throughout, it is now for the first time observed that there is a considerable hardness variation within a given grain.

It is, of course, impossible to state the reason to which these hardness variations may be attributed. There appears to be a certain probability that they may be due to an uneven distribution of the manganese content, which in this iron is comparatively high (0.45%). As regards manganese, it is well known that this substance, at least when present in large amounts, has a great tendency to be irregularly distributed, as was established by Wohrman<sup>(12)</sup> and by Hall.<sup>(13)</sup> Any variation in the manganese content may, of course, imply a variation in other impurities also. Thus, the hardness variations—being of the same character in several micrographs—may not be definitely attributed to variations in the carbon content alone, but they might be of interest anyhow.

Since, however, the assumption of the variability of quenched-steel points in itself did not appear acceptable, tests were made with a 120° *conical Seco point* which had been carefully ground in the lathe. The rulings thus obtained ( $l = 5 \mu$ ) are reproduced in Fig. 35. The ruling is rather uniform and shows several hard narrow bands in which cementite may generally be discerned. Such a narrow band is reproduced at a higher magnification in Fig. 36. In this case it was not possible to discern any free cementite.

Fig. 35 and also Fig. 36 show a large number of dark points. These do not represent any inclusions, but are iron dust carried along by the Seco point and deposited at the ends of the lines like a "moraine" (Fig. 37). (That Seco, unlike the other materials used, should exercise such a cutting action is probably due to the fact that this metal, in spite of being sintered, still contains numerous blow-holes, frequently sharp-edged.)

The lower part of Fig. 38 shows a grain which on the right-hand side is bounded by a hard cementite lamella without any visible ruling. On the left-hand side, near to the grain boundary, greater hardness is distinctly seen, though it is not too great to prevent the line from being apparent. In this case the increase in hardness may actually be due to an enrichment of a substance near the



boundary. It can scarcely be attributed to the existence of a cementite lamella.

The same applies to Fig. 39, which shows a boundary on the right-hand side of which a thin cementite precipitation—which here appears dark—is easily distinguishable. All the lines which cut this boundary show that the hardness of the neighbouring grain *increases towards the boundary*.

A feature on Fig. 38 worth mentioning is the occurrence on the lower side of the cementite lamella of numerous broad short secondary lines, giving the impression of particular softness there. A similar feature is visible in Fig. 40. Here, too, this time prior to the passage over an unusually large inclusion, strong secondary scratches are observable, which likewise may give the impression of great local softness. Their position evidently differs from that of the secondary lines for the whole surface.

In both these cases the cause of the phenomenon is probably simply that the point, comparatively blunt in itself, when passing an obstacle is subjected to a *slight momentary tilting*, sufficient to bring into operation some secondary point not otherwise acting. This phenomenon, thus, is only to be regarded as a vibration of the ruling point.

Another feature, apparently difficult to explain, is to be seen in Fig. 41. On passing a slag inclusion no scratch whatever is to be observed on it. This may not be due to any specially great hardness of the inclusion but rather to great brittleness; probably the slag consisted of an oxide and sulphide phase, of which part had broken loose. The micrograph further shows a narrow cementite portion, causing sharp interruptions in the ruling.

Fig. 42 illustrates an extremely narrow harder line where no cementite could be observed.

Further, in Fig. 43 is reproduced a ruling obtained with a Seco point, showing remarkably great regularity of ruling which is not sensibly affected by hollows, and continuing behind inclusions which had broken loose. It may be observed that the portion immediately beyond the inclusions seems to be softer than the material in general.

### C.—*Sclero-grating Tests on Lead Containing Some Nickel.*

It is known that lead containing some iron preserves a fine grain structure. It appears possible that this might depend on the presence of a higher iron content in the boundaries which might be supposed to cause greater hardness. Some attempts to introduce a sensible amount of iron into pure lead (Kahlbaum) gave no positive result. Preference was therefore given to an addition of nickel, which is more soluble in lead than iron (*cf.* Hansen <sup>(14)</sup>).

Nickel, therefore, was added to the lead by stirring a nickel wire round in strongly heated lead. An analysis (made by R.

Treje) gave a nickel content of 0.025%. This fine-grained material was heated, as a rule, for 2 days at 230° C. in order to give an opportunity for the nickel to become enriched in the boundaries.

It often proved difficult to prepare the surface of the specimen so as to make it sufficiently smooth and flat for the sclero-grating. The best result was obtained thus: The specimen was cut under oil in a hand "chipper" (called "Rapide Lime")—no rigid microtome being available—using a knife, made for the purpose, as sharp and free from scratches as possible and maintaining a thin cutting depth. The knife was ground, using a suitable support, on a rotating lead disc with coarse emery and then on a rigid disc with fine emery. The polishing was done on a pitch disc using finest  $\text{Fe}_2\text{O}_3$ . Finally the rough edge was removed by means of a piece of wood (pear-tree). The underside of the knife edge in particular required careful treatment.

The surfaces produced were comparatively free from cutting scratches; those to be seen in Fig. 44 are due, at least to a great extent, to the fact that the lead, in spite of the oil, adhered to the surface of the knife. On this account it was necessary always to clean the edge with a piece of wood between two cuts.

After cutting, the specimens were generally reheated (24–48 hr. at some 230° C.). Thereby the small secondary grains formed on cutting grew to form rather large grains (Fig. 44). Here the old etched grain structure is to be seen partly unchanged (etched with acetic acid and hydrogen peroxide).

In order to avoid oxidation of the cut surface, the specimen was kept during heating in a sealed evacuated glass tube.

After heating, the sclero-grating was done without further treatment of the surface of the specimen. In a few cases, however, the surface was reground on fine blotting paper moistened with benzene, followed by polishing on a rotating perforated disc clad with flannel and using magnesium oxide nearly free from carbonate (with glycerine).

A certain amount of flow was frequently observed. A clean structure was sometimes obtained by subsequent heating to 230° C.

The first rulings showed that the metal had a strong tendency to stick on the ruling point, as it had done before on the knife. This resulted in rather unequal and even interrupted rulings. Balls of surface material carried along and thrown off caused the point to be deflected at the following ruling. This throwing-off of loose metal occurred particularly at the commencement and at the end of every cutting.

This adhesion of the lead to the point decreased considerably when a thin high-grade watch oil was used (Fig. 45;  $l = 10 \mu$ ,  $p = 0.05 \text{ g.}$ ). The oil, however, was found to attack the specimen slightly, revealing a fine grain structure due to the cutting. The oil, moreover, increased the effective pressure somewhat, as had been the case with iron.

In the micrograph a clear difference of hardness between different grains can be seen. This difference is more or less distinct on different rulings, which must be due to a certain variability of the point, caused by material from the metal surface still adhering to the point.

In spite of repeated trials, no hardness increase in the *actual boundaries* could be established. If it does exist in lead, such a hardness increase in the boundaries is obviously very slight. The concentration of nickel in the boundaries aimed at was, however, only trifling. An attempt to reveal such an actual enrichment of nickel by the use of the spot tests according to F. Feigl failed.

The etching effect often produced by the watch oil used was interesting. As seen in Fig. 46 (etched at room temperature for 20 hr.), the oil exercised a double action. On the one hand, definite but weak grain boundaries are revealed; on the other hand, certain areas contain comparatively large etching pits which are evidently situated around certain of the boundaries. Parallel tests on pure lead without any addition of nickel—though with not quite the same heat treatment—showed similar etching pits but rather evenly distributed over the whole surface. It does not seem unreasonable to suppose that the areas with etching pits in Fig. 46 may be related to an uneven enrichment of nickel there.

With regard to other etching tests, hot concentrated nitric acid was found to passivate large portions of the surface of the lead. At isolated points, however, this broke down and attack occurred (Fig. 47). It is rather striking that these points of attack form certain areas analogous to those in Fig. 46. This might also suggest an enrichment of nickel along the boundaries, but it might have other causes.

#### D.—*Two Investigations concerning the Sclero-grating Method.*

##### (1) *Testing the Method on an Artificial Sample.*

Before testing the grain boundaries of other metals it was considered necessary still further to increase the sensitivity of the method.

*Artificial Specimens.*—Tests were made with two plane specimens of copper soldered together with silver solder—the microscopical hardness of which exceeds that of copper. *No hardness increase could be observed in the solder layer, which was, of course, extremely thin.*

Artificial samples containing slightly harder inlaid layers of a varying thickness ( $0.5\text{--}0.7\ \mu$ ) were prepared by using plane nickel-plated pieces of brass, which were screwed together, cross-ground and polished. The hardness of the brass may be estimated at 50 or 55 Brinell, that of solid nickel at about 60 Brinell, while an electrolytic nickel coating is probably slightly harder. Thus, the hardness differences were not great.

Some sclero-gratings (90° Seco cone) at different pressures on such a test specimen containing a (combined) thickness of nickel of about 5  $\mu$  were made. The results for the higher pressures (0.50 and 0.70 g.) are to be seen in Fig. 48. This will be discussed later.

*Cam for a Low Ruling Speed.*—It was desirable to employ speeds of ruling lower than those obtained earlier with the gearing provided. This was realised by means of a cam, which was attached to the driving shaft and was connected with the ruling mechanism by means of a jointed arm and disc. The disc was pressed by a spring against the periphery of the cam, the motion of which was thus transmitted to the ruling mechanism. The cam was designed to give first a long period with a slight regular rise corresponding to the actual ruling, then came a sharp drop, and finally a marked rise, causing the ruling mechanism to be raised from and subsequently lowered on to the surface of the specimen. Thus with this cam it was possible to use a greater portion of the total time of revolution for the actual ruling than was the case earlier; in this way the ruling speed was decreased to 0.40 mm. per sec., while previously the minimum had been about 1 mm. per sec. Still lower ruling speed was obtained by hand operation.

It was found that all the rulings were *somewhat, though only slightly, narrower* on the nickel layer. On the other hand, no definite difference could be observed between the rulings obtained at different speeds.

As regards the ruling speed, therefore, it is sufficient to say that it should not be so great that the point starts jumping as soon as it reaches an unevenness. The smaller the pressure and the harder the object, the lower should be the speed chosen. According to Gillett <sup>(15)</sup> the cutting speed should not exceed 0.066 mm. per sec. for metals softer than 60 C Rockwell and 0.044 mm. per sec. for harder materials. The fact that much greater speeds could be used here is probably due to the reduction of the mass of the ruling device.

*Varying Pressure ; Critical Sensitivity.*—A new series of rulings was obtained with a pressure varying from 0.50 to 2.0 g., the same conical Seco point as above being used. At the lowest pressures, up to  $p = 1.10$  g., scarcely any difference in width was observed—unexpectedly enough. A clear difference of hardness appeared at  $p = 1.30$  g. This was obviously due to the fact that at this increased pressure the point used no longer behaved as a geometrically uniform one; instead, an adjacent secondary point came into action, which gave rise to a ribbon-like appearance on the ruling on the brass. On passing the nickel layer the slightly greater hardness caused the *secondary point to cease acting*, which produced a strikingly great difference in the width of the ruling.

For the point in the position as used,  $p = 1.30$  g. obviously represented a *critical pressure*. With the pressure  $p = 1.50$  g., the



primary and secondary points worked in conjunction even in the nickel layer, so that no striking diminishment of the width occurred there, though it was quite visible. With the highest pressure ( $p = 2.0$  g.), the narrowing of the ruling was more apparent.

It follows from this that even a specimen with the coarseness of the nickel layer in question does not show any clear hardness difference with a very low pressure. *The difference of hardness appears with great sharpness only at a special critical load.*

The phenomenon of the secondary line appears with very great distinctness in Fig. 48. Thus, with  $p = 0.40$  g., there was only one uniform line, which was slightly narrower in the nickel layer (not shown in the illustration). At  $p = 0.50$  g., however, a secondary line appears too which in this case is comparatively distinct from the main line, the two constituting a *line pair*. In the pair to the right the secondary line shows an interruption or break, the length of which equals the length of the nickel layer ( $5 \mu$ ). The position of the break, however, does not coincide with that of the layer. This is obviously due to the secondary point being situated slightly forward of the primary point in the ruling direction. The "angle of phase" here amounts to about  $\alpha = 42^\circ$ . (This signifies that the point would have to be turned through  $42^\circ$  counter-clockwise in order that the primary and the secondary points might be in the same perpendicular plane as the ruling direction, which of course facilitates interpretation.) This interruption in the secondary line may also be seen, though less plainly, in the pair of lines to the left.

For  $p = 0.70$  g., interruption of the secondary line no longer occurs, though the narrowing is easily visible. Consequently in this case the critical pressure is around  $p = 0.50$  g.\*

A series obtained with a diamond point at the constant pressure of  $p = 0.12$  g. is illustrated in Fig. 49. The point in this case possesses a secondary peak nearly as well developed ( $4.5 \mu$  to the right of the primary peak). In this case the secondary peak by suitable rotation has been brought "into phase" with the primary peak ( $\alpha = 0$ ). On the basis of some preliminary series, the pressure had been adjusted to nearly the critical value ( $0.10$ – $0.15$  g.).

On the whole, the critical sensitivity aimed at does not appear here. In one case (the fourth pair of lines) a plain interruption of the secondary, right-hand line is to be seen. *This interruption, however, only concerns the upper of the two adjacent partial layers of the nickel.* (Their border line may be seen weakly.) Thus, one gains the impression that the upper nickel layer possesses a somewhat greater hardness than the lower, but nothing definite can be said.

In any case it is obvious that the difference in hardness between the main mass and the nickel layer, which appears dark in Fig. 49 owing to the use of a suitable yellow filter, is comparatively small.

\* A slight waviness in the line in Fig. 48 is due to slight damage to one of the springs.



Another series made on such samples was obtained with a 90° Seco point, which had been deliberately blunted by drawing it across a carborundum hone. This was done in order to see whether a specially high sensitivity might be obtained by the presence of a great number of secondary peaks. The grating obtained was rather irregular, owing to the working of the different peaks (possibly caused by the successive formation or breaking loose of small fragments). In any case the greater hardness of the nickel also stood out better, as had generally been the case before.

It was interesting to note the extremely regular vibration of the primary lines, though, strangely enough, not of the secondary lines. This vibration was probably due to the carborundum hone having given rise to regularly spaced unevennesses, which on ruling caused vibration of a very high frequency.

*Conclusion.*—It may be considered that the main result of these experiments on specimens containing an artificial inclusion is to show that the ruling method still leaves a good deal to be desired, in that in many cases inclusions known to be harder have been shown up only faintly. The results so far obtained, negative on the whole, as to the occurrence of the greater hardness anticipated in the grain boundaries are therefore in no way to be regarded as evidence that such greater hardness does not exist.

## (2) *A Detailed Investigation of a Diamond Point and its Operation.*

On the basis of the investigations into the sensitivity of a ruling point—especially one of Seco metal—trials were made on the use of the microscope for identifying those peaks of a point which under given circumstances exert a ruling action. Such an investigation does not appear to have been carried out before, probably owing largely to the not inconsiderable difficulties involved.

For the purpose a diamond splinter, selected and fixed as described above, was considered to be well adapted. It was characterised by the presence of several ruling peaks. The experimental procedure was as follows: The characteristics of the point were first observed at low magnification and then with the magnification successively increased up to that at which rulings with the point had been photographed. This permitted of direct comparison.

The determination of the characteristics of the point demanded a special procedure, which was rendered possible by a microscope—so far undescribed—supplied by the firm of E. Leitz in conformity with indications furnished by Professor C. Benedicks. Its essential feature is that the illumination can be thrown vertically, from all sides ("ultropak"), or both simultaneously, without any change whatever in the optical parts. The microscope, the stand of which had been partly made in the workshop of the Metallografiska Institut, permitted photographs to be taken by means of a Leitz

"Mikro-Aufsatz" camera at a maximum magnification of 750 diameters. The source of light consisted of small electric incandescent lamps (8 V., 0.6 amp.) supplied with the instrument; these necessitated rather long times of exposure, especially with vertical illumination. Quite sharp photographs were obtained in any case when the microscope was mounted on a damping base (tennis balls).

A condition necessary for the carrying out of the work was that the point to be investigated should be fitted in an object-holder carefully guided and with a spring yielding support; without this safety device there was a risk of damaging the front lens, especially with the strongest objective (oil immersion with a magnification of 75 diameters and a free distance 0.51 mm.).

Fig. 50 illustrates the diamond splinter as seen under vertical and "ultrapak" illumination. No real idea of the position of the highest peak is obtainable here, and it was not until a much higher magnification was used that identification became comparatively easy (Fig. 51).

While the ultrapak illumination gives the relief in its entirety the vertical illumination has the advantage that the highest peaks—on account of their horizontal tangential plane—appear light, which permits of a much sharper definition of the highest peaks than with ultrapak illumination.

By taking advantage of the fact that the two methods of illumination complement one another and by focusing direct, the positions of the highest peaks in Fig. 51 have been located with certainty. The highest peak is marked  $A_1$ , while the adjacent peak  $A_2$  is slightly (less than  $1 \mu$ ) lower.

A ruling at a very low pressure ( $p = 0.30$  g.) made in the direction indicated by the arrow  $R$ , photographed at the same magnification, is placed in the correct position in Fig. 51 (a); towards the top is a sharp deep line with slightly uneven edges (marked in white) and a narrow but likewise sharp secondary line. *It is evident from the composite illustration that the former line was formed by the highest peak  $A_1$  of the point and the secondary line by  $A_2$ .* On account of the low pressure no other lines appeared.

In further experiments at a higher pressure the point was damaged, particles being split off, so that after this the point may be considered to be a new one.

With the highest magnification used and in vertical illumination Fig. 52 (b) was obtained. Here three outstanding peaks,  $A$ ,  $B$  and  $C$ , are to be seen by the vertical light reflected from them. In the same way a large field situated slightly lower is visible. Under ultrapak illumination, Fig. 53 (b), the light peaks  $A$  and  $C$  are easily visible, while the peak  $B$  has a remarkable small wart-like projection.

At a lower pressure ( $p = 2$  g.) the ruling shown in the composite illustration Fig. 52 (a) was obtained. *Very good agreement*

*between the three lines and the positions of the peaks is to be seen here.*

Using a higher pressure a ruling was obtained, the commencement of which is shown in Fig. 53 (a). Here it is naturally more difficult to establish a close agreement with the positions of the peaks. It is noteworthy that the large light horizontal field already mentioned has obviously now come into operation.

This diamond point investigation has proved that, thanks to the simultaneous availability of both kinds of illumination, *it is possible to establish agreement between the configuration of the ruling point and the resulting ruling.*

It is therefore possible to judge in advance, at least to some extent, the ruling capacity of a point and to determine its most appropriate setting.

#### E.—*Sclero-gratings on Aluminium.*

It was thought that aluminium would be appropriate for the grain-boundary investigation on account of the hardness difference which ought to appear between the ground-mass of the aluminium and the hard compounds such as  $\text{Al}_3\text{Fe}$ ,  $\text{Al}_2\text{O}_3$  and—probably the hardest—the nitride  $\text{AlN}$ . Hence a number of different brands of this metal were tried, from the purest aluminium available to the ordinary commercial product. These were heat-treated for different periods and at varying temperatures, partly in air and partly in nitrogen, as will be described later.

It proved extremely difficult to obtain on aluminium a surface satisfactory for the sclero-grating, probably on account of the hard aluminium oxide which is always formed. Besides, aluminium possesses great softness and as a rule a great number of inclusions, which easily come loose during grinding and scratch the surface.

On account of the surface oxidation, the anticipated hardness difference between the compound  $\text{Al}_3\text{Fe}$  and the bulk might be more difficult to observe.

The best surface on aluminium is said to be obtained by cutting, using a very steady microtome and good knives (*cf.* Berglund <sup>(16)</sup>). After such a cutting it is, however, necessary to resort to polishing, frequently preceded by grinding.

A rather good surface was actually obtained simply by grinding and polishing. The grinding was first done with emery paper moistened with paraffin and methylated spirit, and then on a stearine disc with fine emery. The polishing was done first with the metal polish "Geolin" and spirit on a soft flannel and finally with magnesium oxide and water.

The great adhesion between the metal and point likewise caused great difficulty when ruling, inasmuch as this was rather irregular. This drawback, however, was remedied by ruling under a liquid, for which purpose watch oil, olive oil and alcohol all proved useful.

The adhesion of the metal to the point was decreased in particular when using alcohol, but this liquid could not be employed for more than very short periods of ruling, as the polished surface was easily attacked.\*

(1) *Metal Heat-Treated in Air.*

A commercial aluminium sheet, containing 0.15% of iron and 0.13% of silicon, after suitable heat treatment gave a material which appeared to be suited to the investigation.

The plate had been stated to be hot-rolled down to 8 mm. and then cold-rolled, parallel with the direction of the hot-rolling, down to 3 mm. It was now heated in air for  $\frac{1}{2}$  hr. at 600° C. to bring about homogenisation, was then stretched 3–6% of its length so as to produce the grain growth desired and was finally annealed for various periods, from 2 to 20 hr., at temperatures varying between 600° and 650° C.

The material found most suitable for the ruling had been stretched 6% and then annealed for 6 hr. at 650° C. It showed very thin, frequently straight precipitations of  $\text{Al}_3\text{Fe}$  in the boundaries, partly leaving spaces where no precipitation could be observed and where a molecular enrichment might be supposed to exist.

On this material a number of sclero-grating rulings were made. When a diamond splinter was used, with  $p = 0.35$  g., the rulings did not appear to be much influenced by the precipitations of  $\text{Al}_3\text{Fe}$ . Still less could a hardness increase be observed in the boundaries free from the  $\text{Al}_3\text{Fe}$  phase.  $\text{Al}_3\text{Fe}$  gave the impression of being soft as a substance, at least in comparison with  $\text{Fe}_3\text{C}$ .

(2) *Metal Heat-Treated in Nitrogen.*

In order to obtain, if possible, in the boundaries the very hard compound  $\text{AlN}$  instead of  $\text{Al}_3\text{Fe}$ , some of the aluminium samples used earlier were heat-treated in a stream of nitrogen. The nitrogen had been freed from oxygen by means of glowing iron. After annealing in nitrogen, further annealing was carried out in air, in order to permit any nitride formed to become enriched in the grain boundaries.

Thus a specimen was heated for 1 hr. at 600° in nitrogen and then in air for 2 hr. at 640°. Analysis for nitrogen showed that originally 0.009% was present, and 0.007% after annealing. The difference is within the accuracy of the analysis.

After the annealing, the specimen was etched with a mixture of fluoric, hydrochloric and nitric acids. The final annealing caused a considerable migration of the boundaries. Thanks to the first

\* The condition for low adhesion between metal and point is expected to be, as Professor C. Benedicks points out, precisely that the liquid should exert a certain attack on the metal.



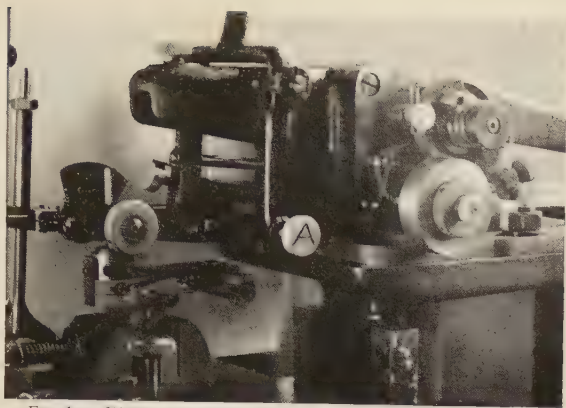


FIG. 19. —Dividing Machine with Ruling Device. About half-size.



FIG. 20.—Sclerograph on Silicon Iron (No. 2). Irregular appearance (caused by cold-working). Diamond point;  $p = 1.5$  g. (approx.),  $l = 10 \mu$ .  $\times 10$ .  $\uparrow R$ .



FIG. 21.—Sclerograph, showing plain grain structure. Iron No. 3; diamond point;  $p = 1.5$  g. (approx.),  $l = 10 \mu$ .  $\times 10$ .  $\uparrow R$ .



FIG. 22.—Partly as Fig. 21, but etched.  $\times 9$ .  $\uparrow R$ .

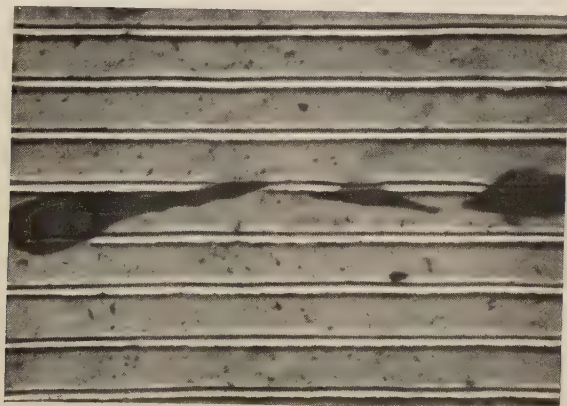


FIG. 23.—Sclero-grating on Iron No. 3, showing hardness difference in non-metallic inclusions. Diamond point;  $p = 1.0$  g.,  $l = 10 \mu$ .  $\times 1000$ .  $\uparrow R$ .

$\uparrow R$  and  $\uparrow L$  indicate direction of ruling and of illumination.  
(Illustrations reduced to two-thirds linear in reproduction.)



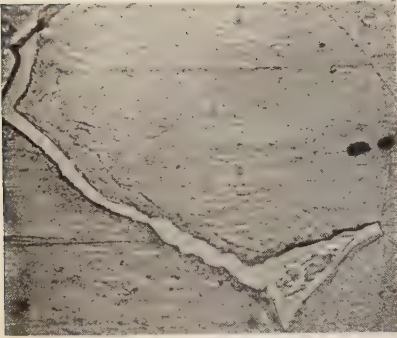


FIG. 24.—Iron No. 5, annealed and etched with 1% nitric acid in alcohol. Large cementite lamella in grain boundary.  $\times 1000$ .



FIG. 25.—Grain Structure of Iron No. 5, etched with nitric acid.  $\times 100$ .

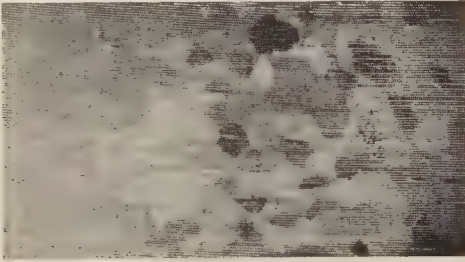


FIG. 26.—Sclero-grating exhibiting grain structure in Iron No. 5. Diamond point;  $p = 0.7-1.0$  g.,  $l = 5 \mu$ .  $\times 100$ .  $\uparrow R$ .



FIG. 27.—As Fig. 26; greater hardness to be seen in some boundaries.  $\times 250$ .  $\uparrow R$ .

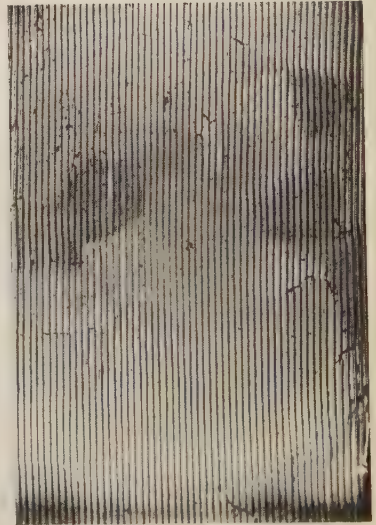


FIG. 28.—As Fig. 27, after etching with alkaline picric acid, showing some free cementite.  $\times 250$ .  $\uparrow R$ .

$\uparrow R$  and  $\uparrow L$  indicate direction of ruling and of illumination.  
(Micrographs reduced to two-thirds linear in reproduction.)

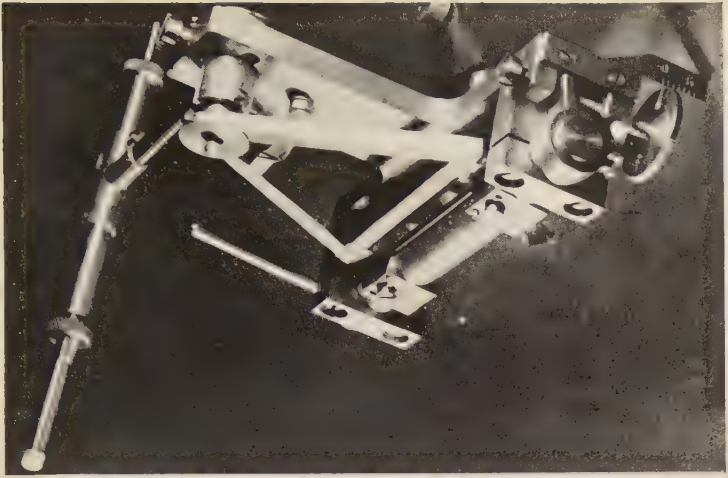


FIG. 29.—Ruling Device, seen sideways from below. About three-quarters size.

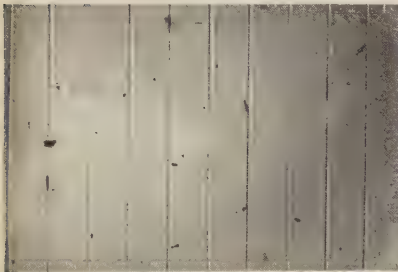


FIG. 30.—Sclero-grating. Good stability and constancy of ruling distance  $l$  ( $= 5 \mu$ ). Iron No. 5; "Seco" cone,  $120^\circ$ ;  $p = 0.20$  g.  $\times 1500$ .  $\uparrow R$ .

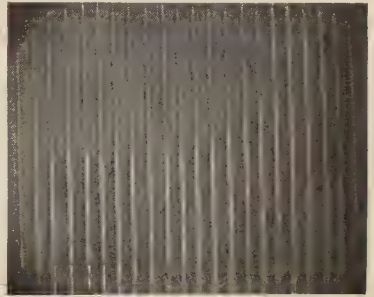


FIG. 31.—Sclero-grating. Hardness difference between two adjacent grains. Iron No. 5; diamond point;  $p = 0.20$  g.,  $l = 2 \mu$ .  $\times 1500$ .  $\uparrow R$ .



FIG. 32.—Sclero-grating. Greater hardness of cementite. Iron No. 5; diamond point;  $p = 0.08$  g.,  $l = 6 \mu$ .  $\times 2500$ ,  $\uparrow R$ .

$\uparrow R$  and  $\uparrow L$  indicate direction of ruling and of illumination.  
(Figs. 30 to 32 reduced to two-thirds linear in reproduction.)

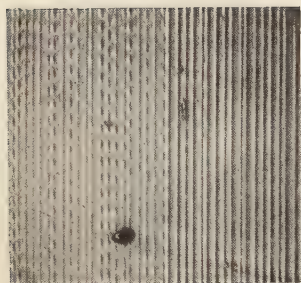


FIG. 33.—Sclero-grating, as improved by the presence of oil (left). Iron No. 5; diamond point;  $p = 0.05$  g.,  $l = 1 \mu$ .  $\times 1500$ .  $\uparrow$  R.



FIG. 34.—Sclero-grating obtained with a Hardened Steel Point. Intergranular hardness differences. Iron No. 5; steel cone,  $60^\circ$ ;  $p = 0.40$  g.,  $l = 6 \mu$ .  $\times 1000$ .  $\downarrow$  R.

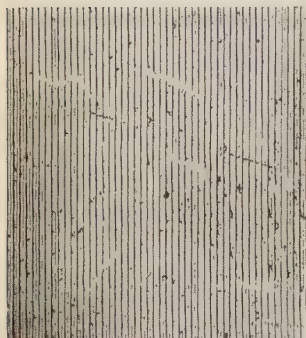


FIG. 35.—Sclero-grating. Harder streaks of cementite. Iron No. 5; "Seco" cone,  $120^\circ$ ;  $p = 1.00$  g.,  $l = 5 \mu$ .  $\times 250$ .  $\uparrow$  R.

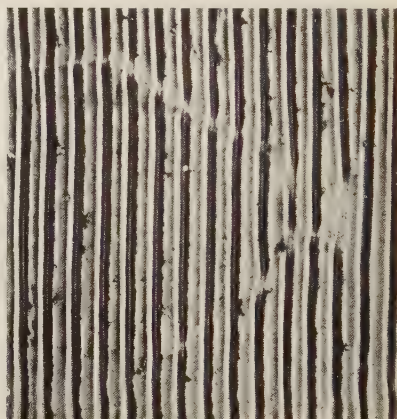


FIG. 36.—As Fig. 35. Harder streak without any cementite phase clearly visible.  $\times 1000$ .  $\uparrow$  R.

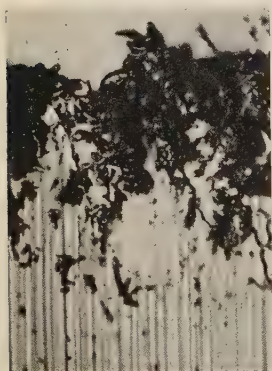


FIG. 37.—Sclero-grating as Fig. 35. End of cuts with "moraine" caused by ruling dust.  $\times 1000$ .  $\uparrow$  R.

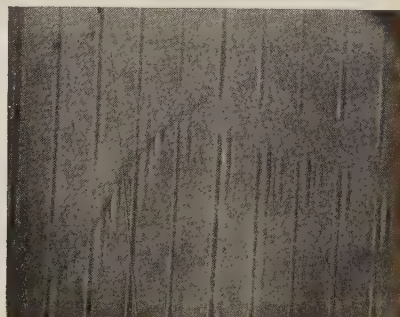


FIG. 38.—Sclero-grating. Considerable hardness differences near boundaries. Iron No. 5; "Seco" cone,  $120^\circ$ ;  $p = 0.40$  g.,  $l = 6 \mu$ .  $\times 1200$ .  $\downarrow$  R.

$\uparrow$  R and  $\uparrow$  L indicate direction of ruling and of illumination.  
(Micrographs reduced to two-thirds linear in reproduction.)





FIG. 39.—As Fig. 38.  $p = 1.5$  g.  $\times 1500$ .  $\uparrow$  R.

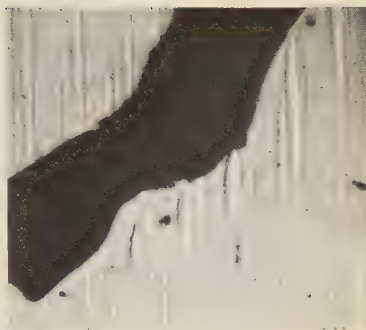


FIG. 40.—Sclero-grating as Fig. 39. Deep mark at a non-metallic inclusion.  $\times 1500$ .  $\uparrow$  R.

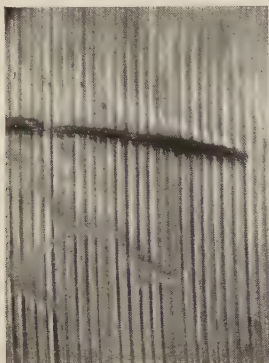


FIG. 41.—Sclero-grating passing a Brittle Inclusion. Iron No. 5; "Seco" cone,  $120^\circ$ ;  $p = 0.30$  g.,  $l = 2$   $\mu$ .  $\times 1000$ .  $\uparrow$  R.



FIG. 42.—Sclero-grating. Harder streak without any visible precipitation. Iron No. 5; "Seco" cone,  $90^\circ$ ;  $p = 0.20$  g.,  $l = 5$   $\mu$ .  $\times 1000$ .  $\uparrow$  R.



FIG. 43.—Sclero-grating. Slightly softer portion near an inclusion. Iron No. 5; "Seco" cone,  $120^\circ$ ;  $p = 1.00$  g.,  $l = 5$   $\mu$ .  $\times 1000$ .  $\uparrow$  R.

$\uparrow$  R and  $\uparrow$  L indicate direction of ruling and of illumination.  
(Micrographs reduced to two-thirds linear in reproduction.)



FIG. 44.—Lead with Nickel Addition. Annealed 48 hr. at  $230^\circ$  C. and etched.  $\times 100$ .



FIG. 45.—Sclero-grating on Lead. Great differences between adjacent grains. Ruled under oil. "Seco" cone,  $90^\circ$ ;  $p = 0.05$  g.,  $l = 10$   $\mu$ .  $\times 500$ .  $\uparrow$  R.

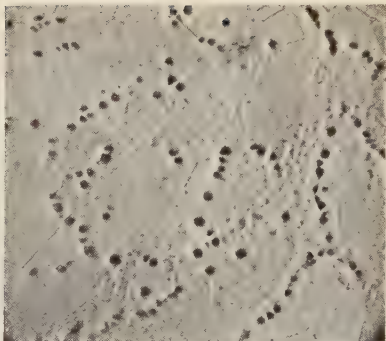


FIG. 46.—Attack on Lead due to Oil used in Ruling. Etching pits along grain boundaries.  $\times 500$ .

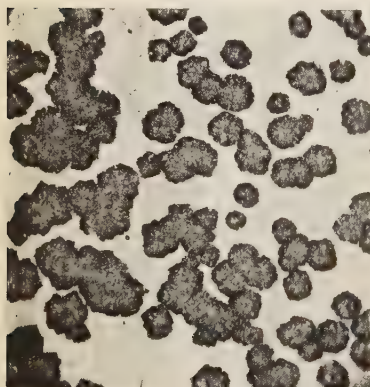


FIG. 47.—Attack by Concentrated Nitric Acid. Effect of passivation.  $\times 100$ .

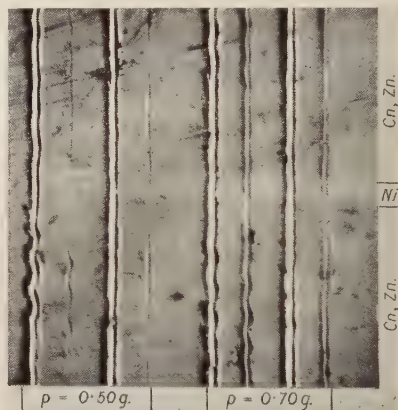


FIG. 48.—Sclero-grating on Brass Specimen containing Nickel Layer. Clear action of secondary peak. "Seco" cone,  $90^\circ$ ;  $p = 0.50$ – $0.70$  g.,  $l = 15$   $\mu$ .  $\times 1000$ .  $\downarrow$  R.



FIG. 49.—Sclero-grating on Brass with Nickel Layer. Slight differences between two portions of the nickel layer. Diamond splinter;  $p = 0.12$  g.,  $l = 15$   $\mu$ .  $\times 1000$ .  $\uparrow$  R.

$\uparrow$  R and  $\uparrow$  L indicate direction of ruling and of illumination.  
(Micrographs reduced to two-thirds linear in reproduction.)



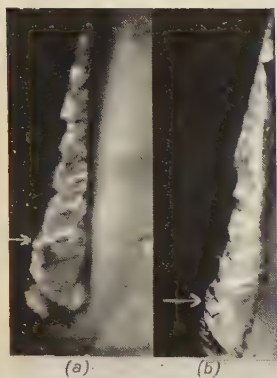


FIG. 50.—Diamond Splinter. (a) Vertical, (b) "ultropak" illumination. Highest portion indicated by an arrow.  $\times 220$ .

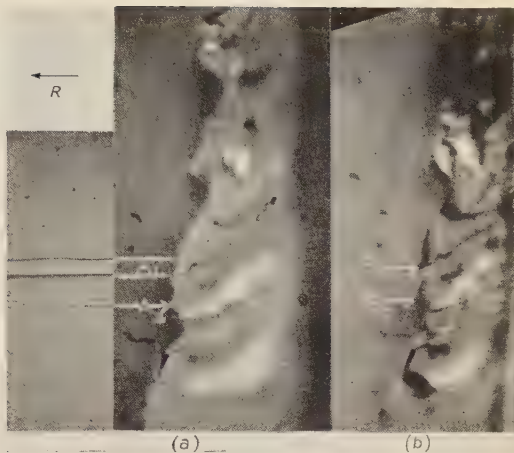


FIG. 51.—As Fig. 50. (a) Vertical, (b) "ultropak" illumination. At this magnification the highest portion is found to consist of two peaks  $A_1$ ,  $A_2$ . The ruling to the left of (a) shows two lines obtained at  $p = 0.30$  g.  $\times 750$ .  $\leftarrow R$ .



FIG. 52.—(a) Ruling ( $p = 2.0$  g.) obtained with the Diamond Splinter seen in (b) (vertical illumination). Its highest peaks,  $A$ ,  $B$ ,  $C$ , correspond well with the lines.  $\times 750$ .  $\leftarrow R$ .

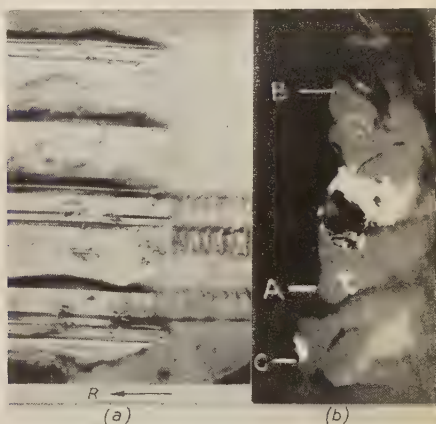


FIG. 53.—Same as Fig. 52. (a) Start of ruling under great pressure. (b) Appearance in "ultropak" illumination.  $\times 750$ .  $\leftarrow R$ .

$\uparrow R$  and  $\uparrow L$  indicate direction of ruling and of illumination.  
(Micrographs reduced to two-thirds linear in reproduction.)

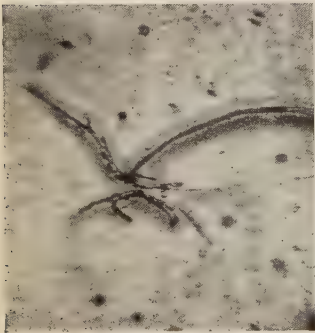


FIG. 54.—Ridges Formed on the Surface of Aluminum after Annealing. They contain a rounded  $\text{Al}_3\text{Fe}$  lamella.  $\times 250$ .

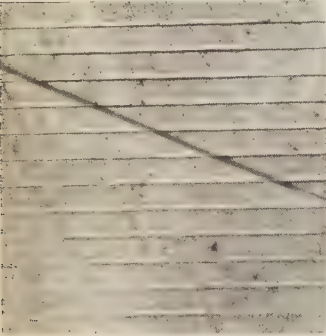


FIG. 55.—Sclero-grating on Aluminum Annealed in Nitrogen. Chisel-like point not very sensitive to hardness differences, but accentuates an  $\text{Al}_3\text{Fe}$  lamella. Diamond point;  $p = 0.20$  g.,  $l = 5$   $\mu$ .  $\times 1000$ ,  $\uparrow$  R.



FIG. 56.—Sclero-grating on Aluminum. Obvious narrowing of the lines when passing a grain boundary. "Seco" cone,  $90^\circ$ ;  $p = 0.50$  g.,  $l = 10$   $\mu$ .  $\times 1000$ ,  $\uparrow$  R.



FIG. 57.—Sclero-grating on Aluminum. Small but evident constrictions (cf. Fig. 58). "Seco" cone,  $90^\circ$ ;  $p = 0.60$  g.,  $l = 15$   $\mu$ .  $\times 1000$ ,  $\uparrow$  R.

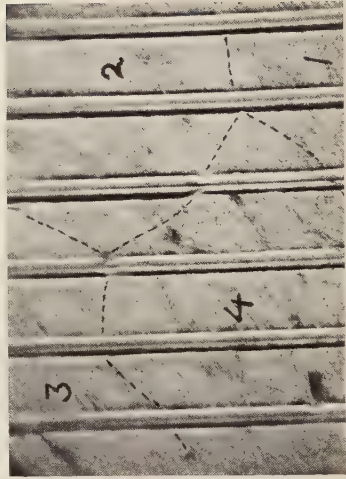


FIG. 58.—Same as Fig. 57. Here the constricted points are connected by dotted lines, possibly marking boundaries between four grains.  $\times 1000$ ,  $\uparrow$  R.

$\uparrow$  R and  $\uparrow$  L indicate direction of ruling and of illumination.  
(Micrographs reduced to two-thirds linear in reproduction.)



FIG. 59.—Sclero-grating on Aluminium. Lower hardness in the neighbourhood of a blow-hole. "Seco" cone,  $90^\circ$ ;  $p = 0.50$  g,  $l = 10 \mu$ .  $\times 1000$ .  $\uparrow$  R.



FIG. 60.—Sclero-grating on Aluminium. Greater hardness at a blow-hole. "Seco" cone,  $90^\circ$ ;  $p = 0.70$  g,  $l = 10 \mu$ .  $\times 650$ .  $\uparrow$  R.



FIG. 61.—Sclerograph caused by Cold-Working by Grinding. Scratches. Diamond point;  $p = 0.15$  g,  $l = 2 \mu$ .  $\times 100$ .  $\uparrow$  R.

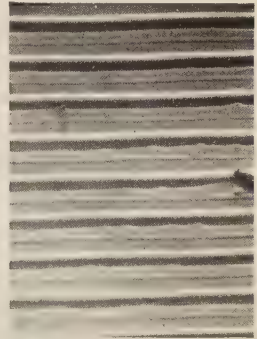


FIG. 62.—Sclero-grating. Constrictions situated along a straight line and evidently due to cold-working. Diamond point;  $p = 0.50$  g,  $l = 5 \mu$ .  $\times 1500$ .  $\uparrow$  R.

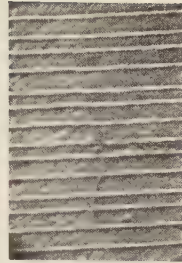


FIG. 63.—Sclero-grating on Iron Annealed in Nitrogen. Greater hardness in a grain boundary, apparently without cementite being present. Diamond point;  $p = 0.15$  g,  $l = 3 \mu$ .  $\times 1000$ .  $\uparrow$  R.

$\uparrow$  R and  $\uparrow$  L indicate direction of ruling and of illumination.  
(Micrographs reduced to two-thirds linear in reproduction.)





FIG. 64.—Sclero-grating on Iron Annealed in Nitrogen. Constrictions along a grain boundary, accentuated by stops in secondary line (*cf.* Fig. 65). Diamond point;  $p = 0.50$  g.,  $l = 5 \mu$ .  $\times 1500$ .  $\uparrow$  R.



FIG. 65.—Same as Fig. 64. Grain boundary marked by a dotted line  $a-a$  together with some less certain boundaries  $b$  and  $c$ .  $\times 1500$ .  $\uparrow$  R.

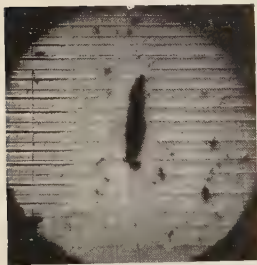


FIG. 66.—Harder Portion near a Sulphide Inclusion. Iron annealed in nitrogen; "Seco" cone,  $90^\circ$ ;  $p = 0.20$  g.,  $l = 3 \mu$  (approx.).  $\times 1000$ .  $\uparrow$  R.

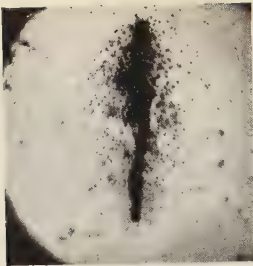


FIG. 67.—Sulphide Inclusion, after etching in alkaline picric acid.  $\times 1000$ .

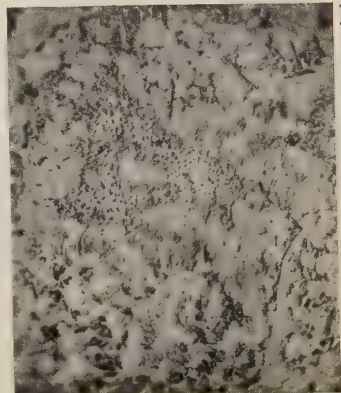


FIG. 68.—Microstructure of Iron Annealed in Ammonia, corresponding to the bracket marked 68 in Fig. 11 (*d*).  $\times 750$ .

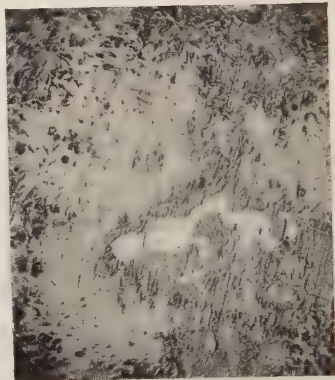


FIG. 69.—As Fig. 68. Structure corresponds to the bracket marked 69 in Fig. 11 (*d*).  $\times 750$ .

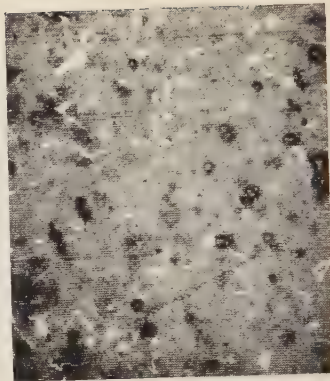


FIG. 70.—Sclerograph on Nitrided Soft Iron;  $d = 35 \mu$  (approx.). Slightly etched. "Seco" cone,  $90^\circ$ ;  $p = 0.50$  g.,  $l = 5 \mu$ .  $\times 1000$ .  $\uparrow$  R.

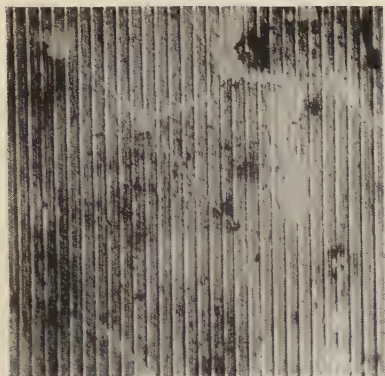


FIG. 71.—As Fig. 70;  $d = 35 \mu$  (approx.).  $\gamma'$  phase harder than  $\alpha$  phase.  $\times 500$ .  $\uparrow$  R.



FIG. 72.—Sclero-grating as Fig. 70;  $d = 30 \mu$  (approx.).  $\gamma'$  portion in a ground-mass clearly harder.  $\times 1000$ .  $\uparrow$  R.

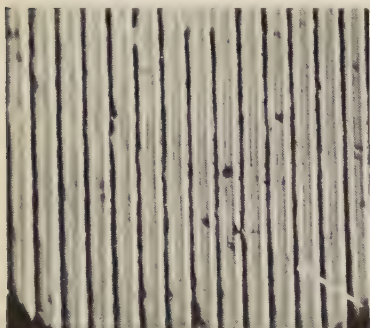


FIG. 73.—Sclero-grating as Fig. 70;  $d = 30 \mu$  (approx.). Harder boundary, indicated by an arrow, in a ground-mass.  $\times 1000$ .  $\uparrow$  R.

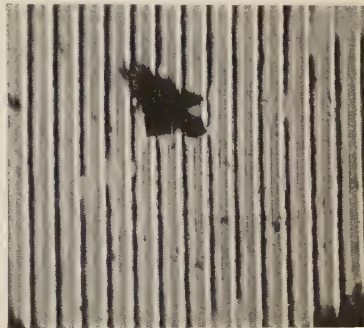


FIG. 74.—Sclero-grating as Fig. 70;  $d = 30 \mu$  (approx.). Very hard non-metallic inclusion, probably  $\text{Al}_2\text{O}_3$ .  $\times 1000$ .  $\uparrow$  R.

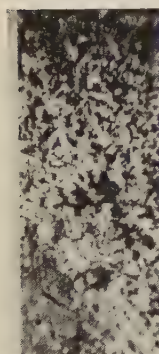


FIG. 75.—Sclero-graph as Fig. 70;  $d = 20 \mu$  (approx.); vertical illumination.  $\alpha$  dark,  $\gamma'$  light.  $\times 50$ .  $\uparrow$  R.

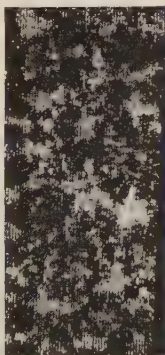


FIG. 76.—Sclerograph;  $d = 20 \mu$  (approx.); "ultropak" illumination.  $\alpha$  light,  $\gamma'$  dark. Nitrided soft iron; "Seco" cone,  $90^\circ$ ;  $p = 1.00$  g.,  $i = 5 \mu$ .  $\times 110$ .  $\uparrow$  R.



FIG. 77.—Sclerograph;  $d = 15 \mu$  (approx.).  $\alpha$ , deeply impressed, dark, in  $\gamma'$  ground-mass. Nitrided iron; "Seco" cone,  $90^\circ$ ;  $p = 0.50$  g.,  $l = 5 \mu$ .  $\times 200$ .  $\uparrow$  R.

$\uparrow$  R and  $\uparrow$  indicate direction of ruling and of illumination.  
(Micrographs reduced to two-thirds linear in reproduction.)



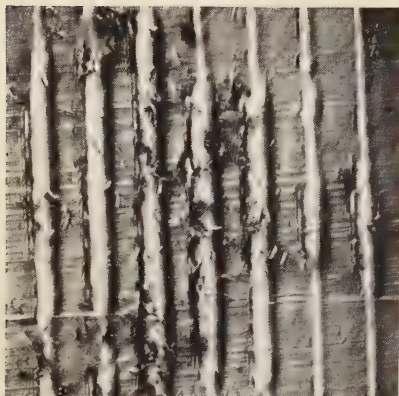


FIG. 78.—As Fig. 77, but at higher pressure, increasing the width differences and causing the appearance of ruling dust.  $p = 0.50$  g.  $\times 2000$ .  $\uparrow$  R.



FIG. 79.—A Natural Sclerograph. Grinding scratches are deep in the  $\alpha$  phase (light). "Ultrapak" illumination.  $\times 220$ .

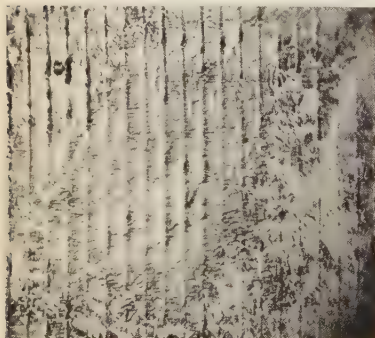


FIG. 80.—Sclero-grating;  $d = 12 \mu$  (approx.). Phases:  $\alpha$  (deep rulings),  $\gamma'$  (dark),  $\epsilon$  (even surface). Slightly etched in nitric acid. Nitrided soft iron; diamond point;  $p = 0.50$  g.,  $l = 5 \mu$ .  $\times 750$ .  $\uparrow$  R.



FIG. 81.—Sclerograph as Fig. 80;  $d = 10 \mu$  (approx.). "Ultrapak" illumination.  $\gamma'$  phase light (deeper scratches),  $\epsilon$  dark.  $\times 750$ .  $\uparrow$  R.

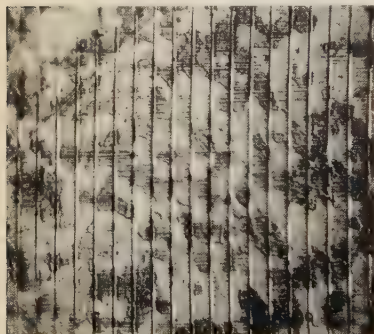


FIG. 82.—As Fig. 81. Vertical illumination; slightly etched.  $\gamma'$  phase dark,  $\epsilon$  phase light.  $\times 750$ .  $\uparrow$  R.



FIG. 83.—Rust Formation on Nitrided Surface caused by Immersion Oil.  $\times 200$ .

$\uparrow$  R and  $\uparrow$  L indicate direction of ruling and of illumination.  
(Micrographs reduced to two-thirds linear in reproduction.)

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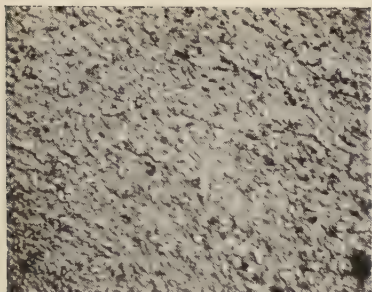


FIG. 84.—Chromium-Vanadium Nitralloy Steel, soft-annealed; etched in nitric acid.  $\times 1500$ .



FIG. 85.—Sclerograph;  $d = 47 \mu$ . Hard irregular lamellæ of  $\gamma'$  in  $a$  ground-mass. Diamond point;  $p = 1.00$  g.,  $l = 5 \mu$ .  $\times 100$ .  $\uparrow$  R.



FIG. 86.—As Fig. 85. Lamella of  $\gamma'$  (grey), harder than the ground-mass  $a$ .  $\times 1500$ .  $\uparrow$  R.



FIG. 87.—Same as Fig. 86, after etching;  $a$  phase seems to be very heterogeneous.  $\times 1500$ .  $\uparrow$  R.

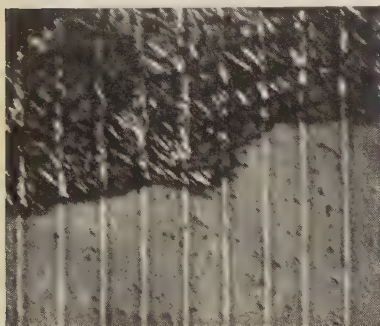


FIG. 88.—Sclerograph as Fig. 85;  $d = 34 \mu$ . Upper part very heterogeneous  $a$  phase, lower part  $\gamma'$  phase. Etched.  $\times 1500$ .  $\uparrow$  R.

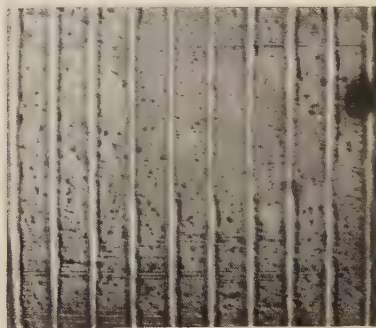


FIG. 89.—As Fig. 88. Somewhat harder portion of  $\gamma'$  in  $a$ .  $\times 1500$ .  $\uparrow$  R.

$\uparrow$  R and  $\uparrow$  L indicate direction of ruling and of illumination.  
(Micrographs reduced to two-thirds linear in reproduction.)



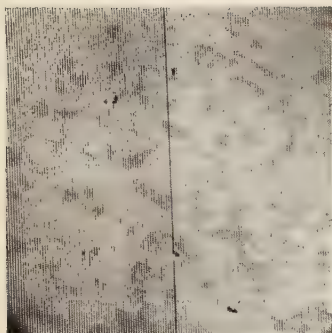


FIG. 90.—Sclero-graph as before;  $d = 26 \mu$ . Ground-mass of  $\gamma'$ , darker portions of  $\alpha$ .  $\times 100$ .  $\uparrow$  R.



FIG. 91.—As Fig. 90.  $\alpha$  portion appearing softer on account of raggedness persisting on the edges of the rulings.  $\times 1500$ .  $\uparrow$  R.

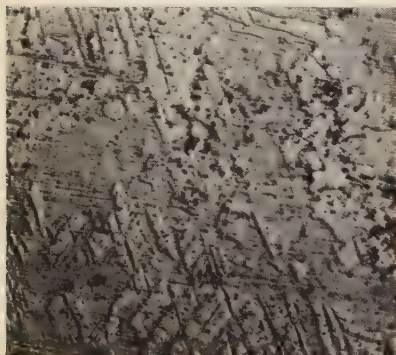


FIG. 92.—Microstructure of Chromium-Vanadium Steel;  $d = 25 \mu$  (approx.). Etched.  $\gamma'$  (dark) showing Widmannstätten structure in  $\alpha$  (light).  $\times 1500$ .



FIG. 93.—Sclero-grating on Chromium-Vanadium Steel;  $d = 10 \mu$ . Etched.  $\gamma'$  ground-mass with small portions of  $\epsilon$  (light, even). Diamond point;  $p = 1.00$  g.,  $l = 5 \mu$ .  $\times 1500$ .  $\uparrow$  R.



FIG. 94.—As Fig. 93. Hardness difference somewhat clearer.  $\times 1500$ .  $\uparrow$  R.

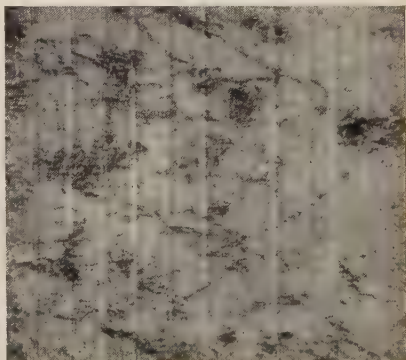


FIG. 95.—Sclero-grating on Chromium-Vanadium Steel;  $d = 3 \mu$ . Etched.  $\gamma'$  phase (dark) appears harder than  $\epsilon$  (light). Diamond point;  $p = 1.30$  g.,  $l = 10 \mu$ .  $\times 1500$ .  $\uparrow$  R.

$\uparrow$  R and  $\uparrow$  L indicate direction of ruling and of illumination.  
(Micrographs reduced to two-thirds linear in reproduction.)



FIG. 96. Sclero-grating as Fig. 95;  $d = 0.1 \mu$ .  $\epsilon$  ground-mass containing hard grains, probably carbide.  $\times 1500$ .  $\uparrow R$ .

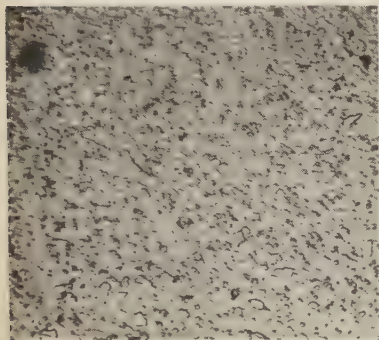


FIG. 97. Chromium-Aluminum Nitralloy Steel, soft-annealed. Etched.  $\times 1500$ .

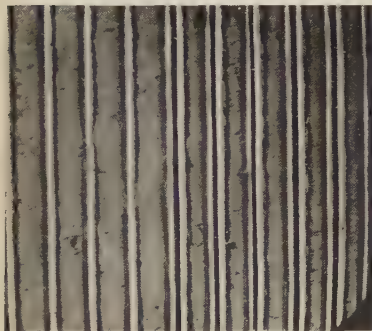


FIG. 98.—Sclero-grating on Nitrided Chromium-Aluminum Steel;  $d = 130 \mu$  (approx.). Considerable hardness difference borne out at low pressure (left). Diamond point;  $p = 1.00$  and  $1.30$  g.,  $l = 5 \mu$ .  $\times 1500$ .  $\uparrow R$ .

$\uparrow R$  and  $\uparrow L$  indicate direction of ruling and of illumination.  
(Micrographs reduced to two-thirds linear in reproduction.)

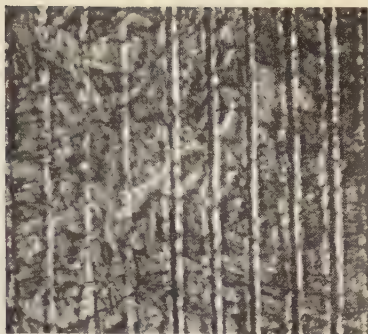


FIG. 99.—Same as Fig. 98. Etched.  $\times 1500$ .  $\uparrow R$ .

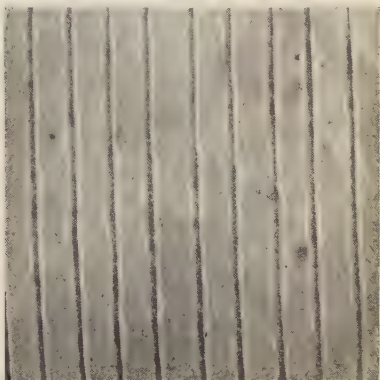


FIG. 100.—Sclero-grating;  $d = 20 \mu$  (approx.).  $\alpha$  phase (harder) and  $\gamma'$  phase. Chromium-aluminum steel; diamond point;  $p = 2.5$  g.,  $l = 5 \mu$ .  $\times 1500$ .  $\uparrow R$ .



FIG. 101.—As Fig. 100. Dark lamellæ of  $\gamma'$  in  $\alpha$ . Etched.  $\times 1500$ .  $\uparrow R$ .



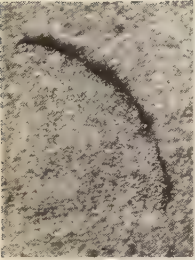


FIG. 102.—Surface Crack on Chromium-Aluminum Steel, occurring after 168 hr. nitriding.  $\times 220$ .

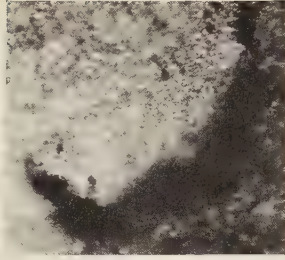


FIG. 103.—Tongue-Shaped Raised Cracking on Chromium-Aluminum Steel.  $\times 220$ .

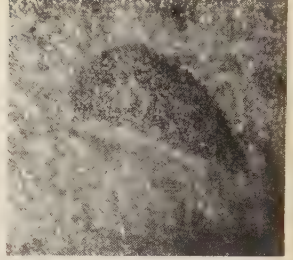


FIG. 104.—Pitting on Nitrided Surface, due to the throwing-off of half of a blister.  $\times 220$ .

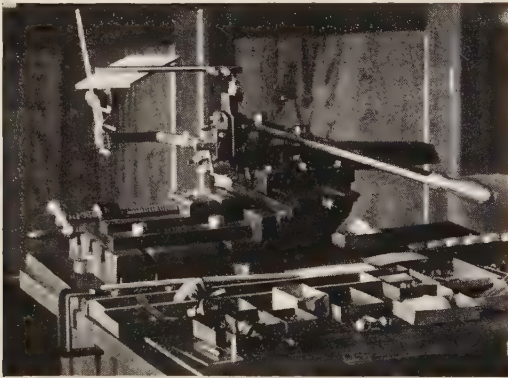


FIG. 105.—Chipper as used for Cutting Experiments. About one-tenth size.

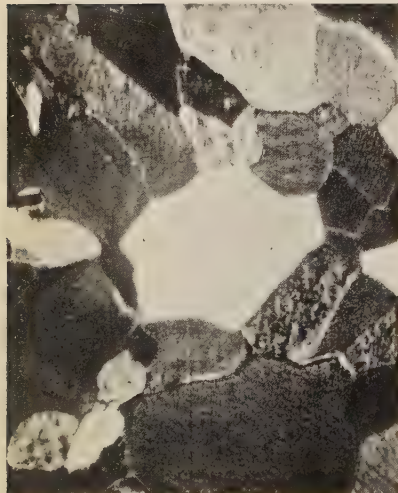


FIG. 106.—Surface of Lead Cut, using a free angle of  $\alpha = 5-6^\circ$ . Grain structure developed as by etching.  $\times 6$ .  $\uparrow$  R.



FIG. 107.—Same as Fig. 106. Existing cutting scratches visible on account of side illumination.  $\times 6$ .  $\uparrow$  R.

$\uparrow$  R and  $\uparrow$  L indicate direction of ruling and of illumination.  
(Figs. 102 to 104, 106 and 107 reduced to two-thirds linear in reproduction.)



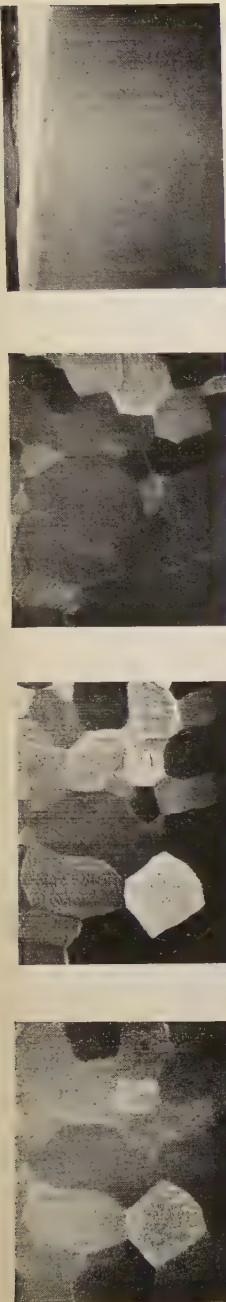
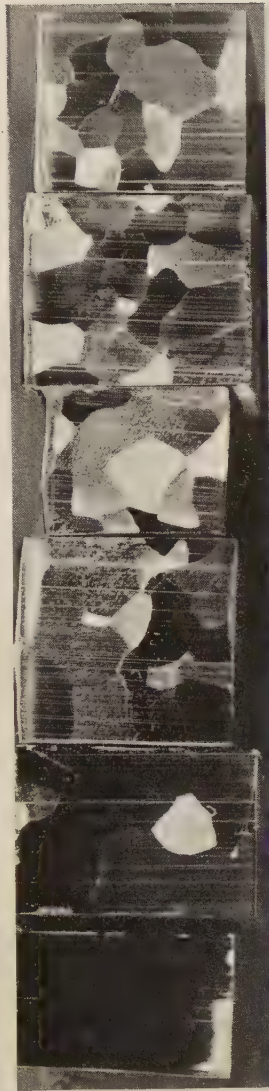


Fig. 108.—(a) Surface of Lead obtained with Cutting Depth of 0.020 mm. ↑ R. (b) Same portion, cutting depth 0.050 mm.; this is preferable. ↑ R. (c) Same portion, opposite cutting direction. ↓ R. (d) Surface obtained when free angle  $\alpha$  approaches 0. ↑ R. ↑ L.



$\alpha$ : 0-0.5° | 0.5° | 2.5° | 4.5° | 6.5° | 9°  
Fig. 109.—Lead Cut Under Different Angles (a);  $\alpha = 4.5$  (6.5) gives best result. About full size. ↑ R.

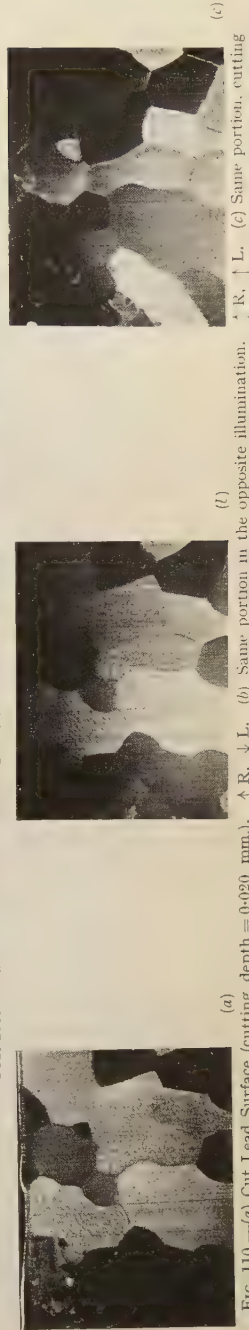


Fig. 110.—(a) Cut Lead Surface (cutting depth = 0.020 mm.). ↑ R. (b) Same portion in the opposite illumination. ↑ R. ↑ L. (c) Same portion, cutting

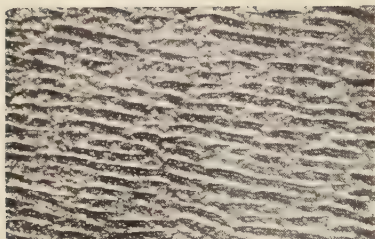


FIG. 111.—Lead Grain, showing a striped surface similar to pearlite (but coarser).  $\times 100$ .  $\uparrow$  R.

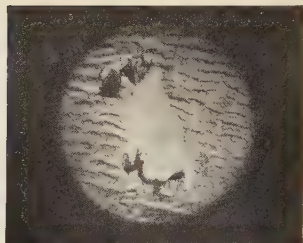


FIG. 112.—Sharply Defined Inclusion in the Grain of Fig. 111.  $\times 100$ .  $\uparrow$  R.



FIG. 113.—Lead Surface obtained on Cutting.  $\times 6$ .  $\uparrow$  R.



FIG. 114.—Same Surface as Fig. 113. Slightly etched (hydrogen peroxide and acetic acid). Interesting cellular substructure revealed.  $\times 6$ .  $\uparrow$  R.



FIG. 115.—As Fig. 114. Another portion with more varied appearance.  $\times 6$ .  $\uparrow$  R.

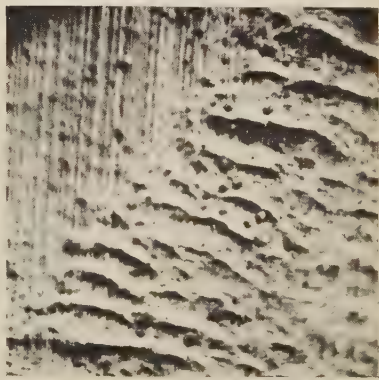


FIG. 116.—The Knife passes a Grain Boundary, causing widely different surface characteristics to appear.  $\times 1000$ .  $\uparrow$  R.

$\uparrow$  R and  $\uparrow$  L indicate direction of ruling and of illumination.  
(Micrographs reduced to two-thirds linear in reproduction.)

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etching, certain grain fields appeared, in that, near the middle, a boundary line, caused by the last etching, became visible.

An interesting phenomenon was the fact that on the original surface, not touched after annealing, there appeared, in addition to a great number of small dark spots, numerous rounded *ridge-like formations*, which were raised some tens of  $\mu$  above the main surface. The character of these elevations may be well observed in Fig. 54. The ridges proved to contain a central part evidently made up of curved lamellæ of  $\text{Al}_3\text{Fe}$ .

The phenomenon should probably be viewed as a *capillary phenomenon*, to some extent comparable to the known property of molten grey iron of expelling graphite flakes, the occurrence of which was rendered possible by the comparatively high annealing temperature.

Fig. 55 shows the result of a ruling. The diamond point used was probably not of a suitable kind. It was chisel-like, causing the hardness increase induced by the ( $1\ \mu$  thick)  $\text{Al}_3\text{Fe}$  lamella to be less pronounced. The reason for the chisel-like character of the point must be the existence of two equivalent peaks, causing nearly the same width of rulings throughout.

The rulings were continued with a hard metal point ( $90^\circ$  Seco cone). In Fig. 56 a constriction of the lines may be seen along a grain boundary. A section of the ruled lines is obviously rounded, giving a higher sensitivity than in Fig. 55. As a cause for the considerable hardness thus revealed (at the upper side of the boundary), the presence of the lamellæ of (the relatively soft)  $\text{Al}_3\text{Fe}$  visible under the microscope must be considered insufficient. Hence, it is natural to assume that the hardness, *at least partly*, is due to a molecular enrichment, say, of nitride; the influence of the ruling direction, however, cannot be entirely excluded.

In another similar structure, an  $\text{Al}_3\text{Fe}$  lamella appeared unusually dark, on account of some oxidation in the air. The constrictions in this case were not so pronounced but were quite visible. A conspicuous scratch which crossed the grain boundary was of interest. *On the rulings no influence of this scratch could be detected*, which shows that the scratches existing on the surface are not so great a drawback as one might expect.

In another analogous case there was a dark  $\text{Al}_3\text{Fe}$  lamella, which owing to its greater thickness than in the previous case had caused some very striking constrictions. At a lower magnification it was possible to observe that the grain boundary continued at other parts; however, a careful examination of the rulings (preferably when seen foreshortened in their own direction) showed some narrowing at several places. The positions corresponded with the observations at a lower magnification.

Thus, this was a case where a *hardness increase*, small though it was, *could be traced in a boundary although precipitation could not be detected under the microscope*.



The results so far of the utmost importance for the main problem are to be seen in Fig. 57. The third ruling from the right at a definite spot changes from a narrower width (lower part) to a slightly greater width (upper part). This, according to the results obtained, proves that this transformation spot corresponds to a grain boundary.

It is noteworthy that in this case *an obvious narrowing of the ruling occurs at this spot* without any foreign inclusion being observable there. Adjoining rulings confirm this.

For the sake of lucidity, Fig. 57 is again reproduced in Fig. 58, but it is now provided with dotted lines, indicating, after a detailed observation, the probable situation of some grain boundaries. The conclusion may be drawn more or less definitely that boundaries exist between (at least) four different grains, marked 1, 2, 3 and 4.

The drawing, of course, cannot be claimed to be very reliable; foreign inclusions, of course, may also occur, though not microscopically visible.

Two more micrographs may be reproduced, which, though scarcely touching on the main problem, yet illustrate the possibilities of the sclero-grating method.

Fig. 59 reproduces the appearance of the rulings in the neighbourhood of a small cavity in the metal. It is obvious here that a roughly elliptical portion on the left-hand side of the cavity appears to be *considerably softer* than the rest of the metal. It does not seem possible to ascribe these broader rulings to a direct influence of the cavity. Similar portions containing a coarser ruling were observed at numerous places adjacent to blow-holes. These portions of softer appearance seem also to be characterised by containing *fewer small inclusions* than elsewhere.

The above gives the impression that the blow-hole to some extent has exercised a purifying action on the metal. (Of course it could not be considered as absolutely excluded that the proximity to the blow-hole may have had some direct influence.)

On the other hand, Fig. 60 shows a central, *considerably harder* portion, adjacent to a blow-hole, with much weaker secondary ruling lines than elsewhere. The greater hardness in this case appears to be due possibly to a *more abundant presence of small inclusions* than in the surrounding neighbourhood. In this case, too, there is a portion giving the impression of greater softness. In this instance, however, it seems rather probable that the blow-hole has exerted a direct influence on the ruling result.

In another case examined a harder portion was found where the additional hardness could obviously be attributed to an abundance of small as well as large inclusions of  $\text{Al}_3\text{Fe}$ , or of other substances.

In spite of a few indications of the influence of the nitride, it must be considered to be rather improbable that a perceptible degree of nitriding had been obtained with the 2 hr. annealing in



nitrogen, which of course is in agreement with the chemical analysis given above.

In order to continue experimenting on the influence of nitrogen it was considered suitable to revert to iron, in which nitriding is better understood and of great practical interest—at least when using ammonia.

F.—*Sclero-gratings on Iron Annealed in Nitrogen.*

The iron which had proved to be the most suitable for the ruling experiments, *i.e.*, No. 5 (Table I.), was annealed, as had been done earlier with aluminium, in a current of nitrogen, in this instance at  $1000^{\circ}$  for 6 hr. The specimen was then cooled slowly to about  $700^{\circ}$  C. and afterwards in the air. The aim was to obtain the formation of the hard iron nitride which might constitute thin enrichments in the boundaries of the grains.

Analysis showed the specimen to contain 0.010% of nitrogen; before the annealing the content was 0.007%. The increase in nitrogen, though not great, seemed to be definite.

Sclero-grating on the material thus obtained, with a given point adjustment and  $p = 0.30$  g., showed very plainly both a *grain structure* and certain *light extremely narrow boundaries*. In some cases it was easy to establish, when using a higher magnification, that the lines were caused by cementite which, on account of the oblique illumination used, was visible even to the naked eye. In other cases, however, it was not possible, even at the highest magnification attainable with an ordinary lens with numerical aperture 1.30, to observe any precipitation of cementite in the light structures.

In order to ascertain whether cementite does occur or not, darkening by means of alkaline picric acid is not quite so reliable as it is for the thinnest cementite; etching likewise is not desirable because of its action on the surface; hence, it is desirable to push the microscopical observation as far as possible.

When using a Zeiss lens of numerical aperture 1.60 belonging to the Metallografiska Institut, it was possible in a few cases to establish that a cementite lamella was present. The fact that this lamella could not be observed when using the lens with numerical aperture 1.30 is probably to be attributed also to the illumination happening to be more suitable when using the lens of higher numerical aperture.

In another portion ruled in a similar way, one of the white lines, which appeared plainly in spite of their narrowness, was found, when using the high aperture, to contain an extremely thin cementite lamella that was otherwise invisible.

In a few cases a rather interesting observation was made. While generally at a lower magnification (100 diameters) the surface had a uniform appearance, in a few cases, where the ruling had

been done at a very low pressure, an irregular *streaky appearance* appeared on the ruling surface (Fig. 61). This streakiness, no doubt, was caused by *cold-working during the coarse grinding of the specimen*, which cold-working had not been removed during the subsequent fine grinding. The ruling in this case was done at a rather weak pressure,  $p = 0.15$  g., while  $l$  was as low as  $2 \mu$ .

The correctness of the interpretation is demonstrated by a micrograph of the same surface at a high magnification (Fig. 62). From the left top down to the right bottom a scratch may be observed here. *All the rulings show on their left-hand boundary the effect of a greater hardness along that scratch.*

In this case the observation gains in lucidity on account of a weak but sensitive secondary line due to a secondary peak, which in this instance obviously had a favourable "phase difference."

In the foregoing some examples of the fact that the scratches in themselves exert a rather weak action have been given. The scratch here visible, no doubt, would not be traceable at all on the ruling had not the metal been slightly harder along the scratch.

Similar evidence of greater hardness is to be seen at several other places on the sample without any scratch being visible. In this case the earlier scratch has evidently been completely ground away. The extremely great sensitivity with which Fig. 61 gives evidence of earlier cold-working recalls the "mechanical detection action," which Benedicks and Mets<sup>(2)</sup> have proved to be due to the cold-working caused by the surface grinding machine, or to Rockwell impressions. In the present case, this sensitivity may be considered as *appreciably greater*. In the former case the structure due to cold-working was best revealed with a pressure on the ruling point of 115 g.; in this case the pressure has scarcely amounted to more than one-thousandth of that.

In the light of the above, the irregular structure found in Fig. 20 for silicon iron may likewise be explained as being due to cold-working.

Fig. 63 shows beautifully the small difference in ruling between a lower grain and a slightly softer and hence lighter upper grain. A clear cementite precipitation along two grain boundaries to the left is visible; on the right-hand side no such precipitation can be observed. Nevertheless, a certain narrowing of the lines can be seen at several places. In this case, however, the specimen has been etched, so that the result may not be conclusive.

Fig. 64 reproduces, at higher magnification, a portion where, at a lower magnification, an obvious grain boundary had been observed. In this case that part of the specimen where the boundary had been observed was characterised by *a clear local decrease in the width of the rulings*, without the least sign of a microscopically visible precipitation.

For the sake of lucidity, on another copy of the same micrograph the sites of these local decreases in the width of the rulings

have been indicated (Fig. 65). Thus, a boundary *a* is well evidenced—particularly by breaks in a secondary line. It is likewise possible to trace certain other boundaries, of which *b* and *c* have been indicated as being most prominent, though the above-mentioned influence of varying cold-working renders the interpretation uncertain.

Along *a* the narrowing is sufficiently obvious for it not to be possible to attribute it to earlier grinding scratches (these form an appreciable angle to the main direction of *a*).

Thus, *after the weak nitriding* obtained by annealing in nitrogen, there are *some portions where the sclero-grating method accentuates a definite hardness increase along a grain boundary without any sign of a foreign phase there being observable.*

Concerning the occurrence of differences in hardness, Fig. 66 shows a sulphide inclusion. The sclero-grating brings out clearly that around this inclusion—especially on its left side—there is an *appreciably harder portion.*

The character of the sulphide inclusion was made clear by etching with alkaline picric acid; in this case, quite a cluster of small particles was found around the inclusion (Fig. 67).

It may be added that in Fig. 66 there is an unusually large number of grinding scratches. It is noteworthy that not one of these apparently rather superficial scratches has any noticeable effect on the rulings, thus substantiating what has been said above.

## II.—SCLERO-GRATING RESEARCHES ON THE PHASES OF NITRIDED CASES. CHECKING BY MEANS OF THE VICKERS METHOD.

### A.—Soft Iron.

#### (1) Introduction.

In the preceding, after numerous negative trials, success was finally achieved in some cases in finding a hardness increase in a grain boundary where microscopically no foreign phase could be observed. This implies support for the theory of molecular enrichment, the probability of which has been pointed out by Benedicks and Löfquist and the investigation of which has been the chief aim of the present work. It would appear less fruitful to continue this examination, which would necessitate the attempt to establish to which substances such a hardness increase was to be attributed.

Instead, it has been considered that the sclero-grating method, as improved on the lines above, should be utilised for the study of some problems of direct importance for practical work. As representing what is nowadays perhaps the most important hardness problem, an attempt has been made to carry out a micro-sclero-metric study of the *phases which occur in the nitrided cases* now so much in use.

Excellent researches, such as those published by Fry,<sup>(17)</sup>

Sergeson<sup>(18)</sup> and Hägg,<sup>(19)</sup> which also embrace certain hardness investigations carried out with the Vickers method, have been made, but regarding the relative hardness of the constituents nothing appears to be known. As the necessary work of making useful sclero-gratings was likely to be rather difficult, it was necessary to start with the simplest case, soft iron nitrided in ammonia, in the same way as for the investigations of, say, Hägg.

## (2) *Phases Occurring.*

The structure formed being rather complicated—probably chiefly on account of the successive formation at low temperatures on the same spot of various phases with increasing nitrogen contents—it was considered well first to give an exposition of the phases which theoretically are to be expected.

Consider an iron mass limited by a plane surface along which the nitriding takes place on account of the presence of a medium having a high nitrogen pressure ( $P_N$ ), such as ammonia. The phases appearing with progressive nitriding are those shown by the equilibrium diagram. This is well known from the investigations of Hägg,<sup>(19)</sup> Eisenhut and Kaupp<sup>(20)</sup> and Lehrer,<sup>(21)</sup> at least for the lower temperatures which are of interest here, as indicated (for high pressures) in Fig. 11 (a). The so-called  $\zeta$  phase, which according to Hägg is possibly only a rich  $\epsilon$  phase and microscopically does not differ from this, has been omitted from the diagram.

If now the supply of nitrogen strictly followed planes parallel to the limiting surface, one would obtain, after some time of nitriding, three adjacent solid layers, namely, first  $\epsilon$  phase, then  $\gamma'$  phase and finally  $\alpha, N$  phase; the last-named phase, rich in nitrogen at first, becomes successively poorer in that element and continuously passes into the unchanged  $\alpha$  phase.

The vectorial character of the diffusion, however, or its difference in definite individual grains, causes certain two-phase areas to be formed, as indicated diagrammatically in Fig. 11 (b) for definite depths  $d$  below the surface.

The corresponding distribution of the nitrogen pressure in the metal is represented in Fig. 11 (c).

The microstructure which is formed is indicated diagrammatically in Fig. 11 (d). The outer existing  $\epsilon$  layer must partly project irregularly into the adjacent  $\gamma'$  phase; hence isolated islands of  $\epsilon$  phase may be expected, having direct connection with the main  $\epsilon$  mass.

In the same way, the  $\gamma'$  phase will have an irregular boundary inwards and show apparently isolated islands in the  $\alpha$  phase, which is now adjacent. The solubility of  $\gamma'$  in the  $\alpha$  phase apparently being much higher at high temperature, a cooled specimen will show not only these  $\gamma'$  islands but also some lamellæ of  $\gamma'$ , or extremely small particles of  $\gamma'$  formed during cooling.

In this sketch of the microstructure, made for the sake of



clarity, the separate phases have been indicated with approximately the different degrees of lightness which characterise them after etching; the  $\alpha$  phase is lightest (though frequently spotted), the  $\epsilon$  phase light grey (shaded) and the  $\gamma'$  phase deep grey (black). This diagram will facilitate the identification of the phases which occur in the nitrided case.

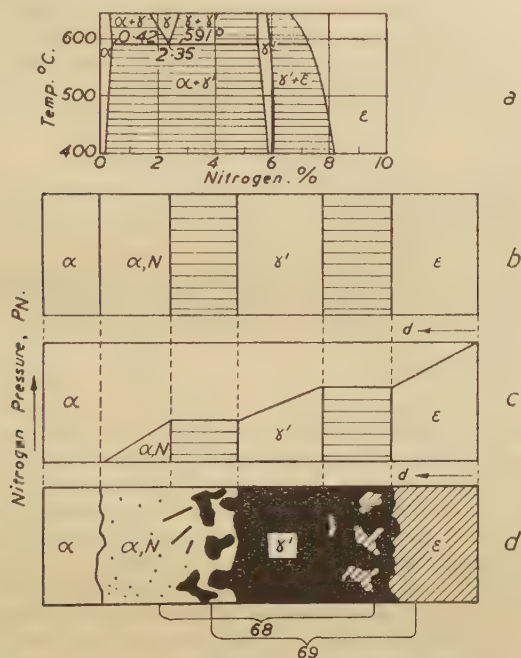


FIG. 11.—Phases Occurring in Nitrided Soft Iron. (a) Lower part of the equilibrium diagram of the Fe-N system. (b) Diagram of the occurrence of the nitrided phases. (c) Successive nitrogen pressures. (d) Diagrammatic representation of the occurrence of the phases.

### (3) Material Used.

Use was made of iron No. 5 (Fig. 25). The nitriding period was 48 hr. at  $520^{\circ}\text{C}$ . in a current of ammonia gas (about  $1\frac{1}{2}$  litre per hr.); the volume of nitrogen and hydrogen was about 10% of the total volume.\* The shape of the specimen was a parallelepiped measuring about  $30 \times 20 \times 12$  mm. The surface was fine-ground and polished before the nitriding, the fine grinding being done on a rotating lead disc (with tungsten carbide, iron varnish being used

\* The author had the opportunity of using the same apparatus as that used earlier by Professor Hägg.

as a binder). It is essential to use a surface as smooth as possible, because scratches induce stronger nitriding.

After the nitriding the main surface was taper-ground, so that the nitrified case could be studied down to a depth  $d$  of about 40  $\mu$ .

In order to characterise the nitrified layer, several micrographs were taken, of which two are reproduced here. In Fig. 68 ( $d$  = approximately 15  $\mu$ ) near the centre there is a light, deeply spotted  $\alpha$  portion in a  $\gamma'$  main mass (light grey). Near the edge of the micrograph there are certain lighter inclusions, which must represent the  $\epsilon$  phase. This microstructure corresponds approximately to the portion of Fig. 11 ( $d$ ) which has been indicated by a bracket marked 68.

In Fig. 69 the lightest part is a small  $\alpha$  portion (here only weakly spotted, partly owing to high focusing); beside it a grey  $\gamma'$  phase occurs, both being situated in a light grey  $\epsilon$  mass, in which there are numerous small inclusions of  $\gamma'$ .

On the diagram this structure corresponds approximately to that indicated by the bracket marked 69, located at a slightly smaller depth below the surface than in the former case.

#### (4) *Sclero-grating Results.*

At a greater distance below the surface, where essentially  $\alpha$  phase occurred, a sclero-grating was obtained; in the main mass thin light spots or boundary portions were frequently observed. In Fig. 70 the light portions are frequently found to be extremely thin and are characterised by narrower rulings than those in the main mass. This latter phase must be  $\gamma'$ . *Consequently, the  $\gamma'$  phase possesses a greater hardness than the  $\alpha$  phase.*

The fact that the  $\gamma'$  phase (in Fig. 70) stands out so clearly may be partly due to weak etching (in nitric acid) attacking the  $\alpha$  phase slightly more than the  $\gamma'$ . The etching has also given rise to some grey spots, which are probably connected with non-metallic inclusions.

The conditions appear better at a higher magnification (Fig. 71). The width of the rulings as measured on the original photograph is about 0.5 mm. in the  $\alpha$  areas and about 0.3 mm. in the  $\gamma'$  areas. In spite of the  $\gamma'$  precipitations being considerably harder, no distinct narrowing of the rulings is observable when crossing the thinnest  $\gamma'$  lamellæ.

At a still higher magnification the hardness difference between  $\alpha$  and  $\gamma'$  stands out clearly (Fig. 72; unetched). This is accentuated by the occurrence of some secondary rulings, which disappear on the  $\gamma'$  phase.

A similar feature is shown in Fig. 73, which is interesting, because at a lower magnification a grain boundary was observed in the direction indicated approximately by the arrow. Though in this case, at least in Fig. 73, no  $\gamma'$  can be observed, a *rather clear*

*narrowing* is to be seen, corresponding to a *greater hardness in the very boundary*.

This should not be attributed to scratches, but of course it constitutes no clear evidence.

In Fig. 74, in addition to comparatively hard  $\gamma'$  areas, an inclusion which is much harder is to be seen. It probably represents an  $\text{Al}_2\text{O}_3$  crystal.

At a depth  $d = 20 \mu$ , Fig. 75 shows a very typical sclerographic structure produced by sclero-grating (without any subsequent etching). The delicate ruling ( $l = 5 \mu$ ), which can scarcely be distinguished in the reproduction, well justifies the designation "mechanical etching." The micrograph was taken in ordinary illumination, so the areas which possess the least width of ruling, *i.e.*, the greatest hardness, appear light. The light constituent, thus, is the  $\gamma'$  phase, which at this depth occurs in approximately the same amount as the  $\alpha$  phase, here dark. The illustration shows rather uneven nitriding.

Another sclerograph is shown in Fig. 76. This, however, was taken under ultropak illumination, hence the portions with deep rulings appear light. In this image, therefore, the  $\alpha$  phase appears light; this image being similar to the preceding one, both phases may be assumed to occur in similar amounts. (Possibly there is some  $\epsilon$  phase.)

At a depth of approximately  $15 \mu$  the sclerograph reproduced in Fig. 77 was obtained. The  $\alpha$  phase, displaying a rather deep ruling, exists in much smaller quantities than before.

At a high magnification, the great difference in ruling width stands out strikingly between the (softer)  $\alpha$  phase and the  $\gamma'$  phase.

At a greater pressure ( $p = 0.50 \text{ g.}$ ), the difference in width is still more striking (Fig. 78); on the  $\alpha$  phase ruling dust is to be seen. The widths in the  $\alpha$  and in the  $\gamma'$  phases on measurement were found to be in the ratio of  $34 : 11$ . *The  $\gamma'$  phase is consequently substantially (say,  $3^2 = 9$  times) harder than the  $\alpha$  phase.*

Knowing this, no difficulty is encountered in noting the hardness with much simpler means than sclero-grating. Thus, Fig. 79 reproduces a portion of the specimen where scratches persist from the grinding, making a natural sclerograph. The illumination here is ultropak. It is clearly evident that certain rather well-defined areas contain deep scratches and hence appear light, while scratches may scarcely be seen at all in other similarly well-defined areas. It is obvious that the *grinding scratches bring out the softer  $\alpha$  phase*.

In the light of this observation it is no longer astonishing that even on an apparently well polished surface the  $\gamma'$  phase is almost free from scratches, while the  $\alpha$  phase (lighter) shows numerous scratches, thus proving it to be softer.

An area about  $12 \mu$  below the surface, where the amount of  $\gamma'$  phase is very high, is reproduced in Fig. 80. After ruling, the

specimen was etched slightly with nitric acid, which might to some extent influence the ruling appearance and render interpretation difficult.

At a few points the illustration shows the very deep rulings which are characteristic of the  $\alpha$  phase. The bulk of the specimen consists of a light-grey  $\epsilon$  phase, in which there is a great number of grey, frequently angular, areas, which must be  $\gamma'$  phase.

A possible hardness difference between the  $\epsilon$  and the  $\gamma'$  phases is of especial interest. Because of the fineness of the structure it is difficult on the micrograph to observe any obvious difference. It is, however, evident—from a few similar micrographs and as a result of ocular inspection—that the ruling width on the  $\epsilon$  phase is sensibly smaller than that on the  $\gamma'$  phase—that is, *the  $\epsilon$  phase is harder than the  $\gamma'$  phase.*

A portion situated at a slightly smaller depth (about 10  $\mu$ )—where the structure consequently consisted of  $\epsilon$  and  $\gamma'$  phases—gave the sclerograph shown in Fig. 81 (unetched). The illumination (ultropak) reveals a very striking difference in hardness between the  $\epsilon$  and the  $\gamma'$  phases. It is easy to decide which of these phases is harder from Fig. 82, in which a similar portion is reproduced under ordinary illumination after a weak etching, which renders the structure visible. It is found throughout that the rulings are *narrower in the lighter  $\epsilon$  phase than in the darker  $\gamma'$  phase.* The widths stand in the approximate ratio of 1 : 1.5; hence it follows, remarkably enough, that the  $\epsilon$  phase is considerably harder than the  $\gamma'$  phase. This signifies that for nitrided soft iron the phases seen, which in the order of decreasing nitrogen content are  $\epsilon$ ,  $\gamma'$  and  $\alpha$ , *give the same sequence when arranged according to decreasing hardness.*

*Thus, the hardness of the phases rises parallel with the increase of nitrogen content.*

This result is in full agreement with the result obtained by Hägg<sup>(19)</sup> when determining the average hardness by the use of the Vickers method, namely, *the hardness decreases from the actual surface inwards.*

In other directions too, good harmony exists with the results achieved by Hägg. The fact that the  $\epsilon$  phase has been observed less here than in Hägg's investigation may be ascribed to X-rays being better adapted to its identification than the microscope. The same applies to the  $\zeta$  phase—for which no indications have been found micro-sclerometrically.

Lastly, a micrograph of a nitrided specimen taken at a depth of about 20  $\mu$  (Fig. 83) is reproduced. During the comparatively short time of 16 hr. the surface was covered with immersion oil, and this has obviously caused a *finely branched rust formation*, which appears scarcely to have been observed on non-nitrided iron. Otherwise, nitrided cases are known to be less apt to rust in air than soft iron, though their sensitivity to acids and halogens is greater than that of iron (*cf.* Sergeson and Deal<sup>(22)</sup>).



B.—*Nitralloy Steel.*

In connection with the investigation on soft iron, it was considered of interest also to gain some knowledge of the variation of hardness occurring in an ordinary nitriding steel. Some micro-sclerometric hardness determinations on nitriding steel, though not related to the hardness of the individual constituents, have been carried out by Bierbaum.<sup>(4)</sup>

The nitriding steels here investigated were a chromium-vanadium steel and a chromium-aluminium steel, with normal contents of other substances; their analyses are given in Table II.

TABLE II.—*Analyses of Nitriding Steels.*

	Chromium- Vanadium Steel.	Chromium- Aluminium Steel.
Carbon. % . . .	0.27	0.37
Silicon. % . . .	0.20	0.34
Manganese. % . . .	0.50	0.59
Phosphorus. % . . .	0.022	0.015
Sulphur. % . . .	0.009	0.005
Chromium. % . . .	2.52	1.38
Nickel. % . . .	0.42	1.92
Molybdenum. % . . .	0.25	0.29
Aluminium. % . . .	...	1.04
Vanadium. % . . .	0.23	...

The specimens ( $50 \times 20 \times 12$  mm.) were pretreated and, after the nitriding, taper-ground in the same way as the soft iron. The depths of the nitrided cases investigated were 0–50  $\mu$  for the chromium-vanadium steel and about 0–500  $\mu$  for the chromium-aluminium steel.

(1) *Sclero-grating Investigations on Chromium-Vanadium Steel.*

Before nitriding, this steel had been soft-annealed and possessed then the extremely fine-grained appearance shown in Fig. 84 (etched with nitric acid in ethyl alcohol).

Nitriding was effected at 520° C. for 48 hr.

The sclero-gratings were made at different depths ( $d$ ) and the following observations were made.

At the depth  $d = 47$   $\mu$ , extremely thin, irregular lamellæ of  $\gamma'$  phase were observed in a ground-mass of  $\alpha$  (Fig. 85). These are considerably harder than the  $\alpha$  phase, which causes them to appear only after polishing (*cf.* the portion on the left of the ruled part). Fig. 86 shows the ruling for such a harder  $\gamma'$  lamella (slightly darker than the ground-mass). It is noteworthy that the  $\alpha$  mass (and also the  $\gamma'$ ) contains a great many small inclusions. The same feature stands out still better in Fig. 87, which shows the same portion but after etching.

For  $d = 34 \mu$ , a sclero-grating is reproduced in Fig. 88 (etched in nitric acid). The lowest portion is  $\gamma'$  phase, the upper part  $\alpha$  phase. The etching reveals that *the  $\alpha$  phase* is obviously far from being homogeneous; in fact it is seen to *contain a great number of hard particles* (there is even a certain similarity to the eutectoid braunite). This may afford the explanation of the striking fact that the  $\alpha$  phase—found above to be considerably softer than the  $\gamma'$  phase—here approaches the  $\gamma'$  phase in hardness.

Fig. 89 shows a  $\gamma'$  portion (grey) in the  $\alpha$  ground-mass. In this micrograph (unetched) the  $\alpha$  phase appears to be sensibly softer than the  $\gamma'$  on account of the well-marked upstanding ragged edge in the  $\alpha$ . The actual difference in width of the rulings on the other hand is much smaller than before (at a greater depth).

For  $d = 26 \mu$ , the sclerograph, Fig. 90, presents a ground-mass consisting of  $\gamma'$  containing smaller isolated portions of the  $\alpha$  phase. The micrograph might give the impression that the  $\alpha$  portions, being darker (under vertical illumination), may be softer. This, however, is not the case. As a matter of fact, it is plainly seen at a higher magnification that such a portion differs from the  $\gamma'$  ground-mass by a certain ragged edge remaining on the one side of the ruling, causing a dark appearance at a low magnification (Fig. 91). On the other hand it is plain that the width of the ruling, though possibly greater in the  $\alpha$  portion (to the right centre), in any case displays but a slight difference.

An adjacent portion, though without any grating, is shown in Fig. 92. The  $\gamma'$  phase is especially clearly visible at the left lower side; it possesses the character of the Widmanstätten structure, and is distinctly dark. (A special green filter was used.)

It is noteworthy that here the grinding scratches appear to be considerably less on the  $\alpha$  phase than on the  $\gamma'$ , indicating, according to the above, that *the  $\alpha$  phase possesses the greater hardness*.

At  $d = 10 \mu$  (Fig. 93) the ground-mass is  $\gamma'$ , with slightly lighter inclusions of  $\epsilon$  phase. The ruling brings out no appreciable difference in hardness between the two phases, but it is obvious that—as might be expected from the observations on nitrided soft iron—the  $\epsilon$  phase is not harder than the  $\gamma'$  phase; on the contrary, *the  $\epsilon$  phase must be slightly softer than the  $\gamma'$  phase*.

In a sclero-grating for a depth of  $d = 6 \mu$  the ground-mass consisted essentially of  $\epsilon$  phase (light) with a smaller amount of  $\gamma'$  phase (dark). On account of the fine distribution, it was not easy to say which of the constituents was the harder. Generally, however, the width of the rulings appeared to be greater in the  $\epsilon$  phase, so that this phase again appeared to be the softer.

A similar portion is shown in Fig. 94. The slightly coarser structure here makes it possible to state that  $\gamma'$  possesses a slightly greater hardness.

For  $d = 3 \mu$  a sclero-grating was obtained as shown in Fig. 95.

It gives the impression that the darker  $\gamma'$  phase is appreciably harder than the main mass (light  $\epsilon$  phase).

The sclero-grating in Fig. 96 was taken on the actual surface ( $d = 0-1 \mu$ ). The small grains here visible, probably carbide, are so minute and so rarely cut by the rulings that it is scarcely possible to draw any conclusion regarding their relative hardness. However, they are in relief in the  $\epsilon$  ground-mass, which decidedly suggests greater hardness.

The fact that they are actually situated appreciably above the surface of the  $\epsilon$  phase was proved in another micrograph taken under "low" focusing, when they appeared much lighter than the ground-mass. Their great hardness was also revealed by the frequent occurrence of "comet tails" <sup>(23)</sup> (a specially marked abrasion on both sides of the hard inclusion, with the ground-mass at the rear of the inclusion in slight relief).

It may be added that it has not been easy to identify the phases, but the interpretations given may be considered to be reliable, especially as they are in full agreement with the micrographs given by Hägg and supported by X-ray analysis.

*Conclusions Regarding the Hardness of the Constituents.*—From the point of view of hardness, the most noteworthy results from the sclero-gratings made on chromium-vanadium steel are as follows.

(1) The  $\alpha$  phase occurring at a rather great depth (such as  $47 \mu$ ) is only slightly softer than the  $\gamma'$  phase, in contradistinction to nitrided soft iron, in which the  $\alpha$  phase is much softer.

(2) The hardness difference in question was found to be still more diminished at a smaller depth ( $34 \mu$ ) and then to be reversed at about  $26 \mu$ , so that  $\alpha$  then proved to be *harder* than  $\gamma'$ .

(3) At a certain depth (about  $10 \mu$ ) the  $\gamma'$  phase was slightly harder than the  $\epsilon$  phase; this difference appeared to increase as the surface was approached (at about  $6$  or  $3 \mu$ ).

This differs entirely from the observations made on nitrided soft iron, in which the  $\epsilon$  phase was harder than the  $\gamma'$  phase.

(4) The highest hardness found was probably that of the many small grains—which might be supposed to be rich in chromium carbide.

Though the value of these observations should not, of course, be over-estimated, knowledge of this special hardness domain, which is of the greatest practical importance, is so slight that a more detailed discussion may be desirable, and in the following an attempt to present a clear exposition will be made.

First of all, the above observations (1) to (3) are illustrated, quite roughly, in the graph Fig. 12, in which the abscissa  $d$  represents the depth below the surface and the ordinate  $H$  indicates (at least qualitatively) the hardness. Starting from the fact that in the equilibrium diagram the  $\gamma'$  area is *extremely narrow* (cf. Fig. 11 (a)), it follows that the  $\gamma'$  phase must possess a *rather constant*

hardness irrespective of the depth. Consequently the hardness of the  $\gamma'$  phase is indicated by the continuous line 1-2, extending across the depth at which (under the nitriding conditions used) the  $\gamma'$  phase occurs. As for the  $\alpha$  mass, observations (1) and (2) signify that its hardness (diagrammatically) may be represented by the line 3-4, intersecting the preceding one at about  $30\ \mu$  and extending to about  $15\ \mu$ . In the same way the  $\epsilon$  phase may be represented by the line 5-6, which (according to (3)) is assumed to increase towards the right.

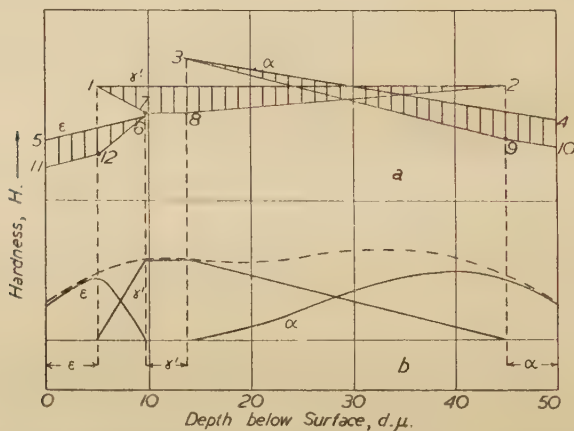


FIG. 12.—Diagrammatic Representation of the Hardnesses of the Microconstituents and the Resulting Total Hardness.

Accepting these qualitative data there is some possibility of estimating the resulting curve of actual hardness. For this purpose let Fig. 12(a) indicate diagrammatically the quantities of the different constituents occurring.\*

Thus, the amount of the  $\gamma'$  phase present may be represented by the vertical distance between line 1-2 on the one side and the three lines 1-7, 7-8 and 8-2 on the other; along the horizontal 7-8  $\gamma'$  occurs to the greatest extent. The amounts of  $\alpha$  phase may be represented by the vertical distance between line 3-4 and the lines 3-9 and 9-10 and, finally, the amounts of  $\epsilon$  phase by the distance between line 5-6 and the two lines 11-12 and 12-6.

It is now a question of adding the (very approximate) hardness increases, which may be expected to be caused by the different phases.

For this purpose Fig. 12 (b) may serve, in which the ordinates

\* This is done in a way equivalent to the well-known method of Tammann, indicating in an equilibrium diagram the amount of eutectics present by means of certain vertical lines.



are regarded as, say, the product of the above quantities of phases and the individual hardnesses of the phases.

Thus, the hardness increase arising from the presence of  $\epsilon$  phase will correspond roughly to the  $\epsilon$  curve drawn; this, of course, must show a maximum at some depth before the disappearance of the  $\epsilon$  phase. The hardness contributed by the  $\gamma'$  phase may be illustrated by the curve  $\gamma'$ , which of course will show a maximum at a depth corresponding to line 7-8. The hardness contribution of the  $\alpha$  phase may be indicated by the curve  $\alpha$ .

If now these partial curves are added together, the dotted curve is produced as an expression, though very rough, of the total hardness to be expected.

As a matter of fact, it appears to furnish an acceptable explanation of the behaviour found by Hruska,<sup>(24)</sup> Hägg<sup>(19)</sup> and others of the hardness distribution in chromium-vanadium steel as determined by the Vickers hardness method. Proceeding from the surface, this consists of first a hardness increase up to a first maximum, and then a weak minimum, followed by a second maximum.

The most characteristic feature may be considered to be that the hardness after nitriding in the case of soft iron is caused by the  $\epsilon$  phase, while the  $\alpha$  phase is quite soft. In the chromium-vanadium steel, on the contrary, the hardness is caused by the  $\alpha$  phase, which obviously contains another nitride phase in a precipitated condition, microscopically visible, but also possibly in a sub-microscopic state.

## (2) *Sclero-grating Investigations on Chromium-Aluminium Steel.*

The original intention was to make sclero-grating investigations likewise on chromium-aluminium steel, which might be the most important in practice. Only a small number of determinations, however, was made.

Fig. 97 (etched in 1% nitric acid) shows the primary, finely spheroidised structure. It gives the impression of containing various phases. No quenching was made.

The steel was nitrided simultaneously with the chromium-vanadium steel (48 hr. at about 520° C., the current of ammonia and the degree of dissociation being the same).

A sclero-grating obtained on the taper-ground surface at a depth of  $d = 130 \mu$  gave the result shown in Fig. 98; two different pressures were used ( $p = 1.00$  g. and 1.30 g.). A few spots stand out, especially at the lower pressure (to the left), having a greater hardness than that of the surface generally. The width of the ruling, generally about 2.6 mm. on the left part of the original photograph, here decreases locally to about 1.5 mm. After etching, the field examined had the appearance shown in Fig. 99.

Thus, at this considerable depth below the surface, where only  $\alpha$  phase may be supposed to occur, light spots do appear, which are

evidently characterised by a hardness greater than that of the ground-mass. This is rather heterogeneous.

It is impossible to decide upon the character of the harder spots; it might be conceivable that they represent portions where the nitride is more highly dispersed than elsewhere (*cf.* Norton,<sup>(25)</sup> Jones and Morgan<sup>(26)</sup>).

At  $d = 20 \mu$ , the sclero-grating in Fig. 100 was obtained. The adjacent area, after etching, is reproduced in Fig. 101. Here dark lamellæ of  $\gamma'$  are to be seen in a ground-mass of  $\alpha$ . It follows from the first micrograph that the  $\alpha$  phase appears to be not inconsiderably harder. This observation is in accordance with that made on the chromium-vanadium steel, as shown in Fig. 12 (*a*) for a smaller value of  $d$ .

Largely on account of the extremely fine microstructure, which rendered the observations very difficult, no further sclero-gratings were produced. On the other hand, a good many hardness determinations were made on this steel by the Vickers method. This constitutes another check on the success of the sclero-grating method.

### (3) *Vickers Hardness Determinations on Chromium-Aluminium Steel.*

Hägg<sup>(19)</sup> has given a Vickers hardness curve down to a depth of 500  $\mu$ . At a lower depth it seems to coincide rather well with the curve for chromium-vanadium steel (though showing greater hardness). At depths greater than 220  $\mu$  Hägg's curves—like several other published curves—undergo an unexpected deflection downwards. It seemed to be of interest to examine the cause.

*Comparison of Methods.*—It was further considered of interest quantitatively to compare the sclero-grating method with the Vickers method. For this purpose determinations were made on a specimen of chromium-aluminium steel, using both methods. The surface, taper-ground, was examined down to a depth of about 160  $\mu$ .

In order to obtain a ruling point as well defined as possible, a 100° conical diamond point was used. Microscopical examination showed that in its original condition it was fairly well formed, but nevertheless at the outermost tip there was a small plane extending to about 4  $\mu$ , the unevenness of which no doubt affected the rulings. Later examination after some use showed that a certain amount of wear had taken place, and a large amount of metal dust was seen on the point.

The widths of the rulings obtained were measured at three points (a few readings at each), using a micrometric ocular (C. Zeiss). The values of the width  $b$  were reduced to values ( $H_r$ ) comparable with the Vickers determinations, using the formula introduced by Bierbaum:<sup>(3)</sup>

$$H_r = a \cdot b^{-2},$$

where  $b$  is given in  $\mu$  and  $a$  is a constant having the numerical value  $10^4$ . For the sake of simplicity this constant has been used

though it might have been natural to evaluate  $a$  so as to give best coincidence with the Vickers measurements made.

The  $H_r$  values so obtained have been plotted in Fig. 13 (crosses) with average values (circles) which have been joined up by straight lines (curve I.). The diagram shows that the scattering of the values is, of course, considerable, especially for small  $b$  values (to the left), but that, anyhow, the sequence of lines, taken as a whole, progresses comparatively regularly, showing a maximum near the surface.

In Fig. 13, further, the Vickers determinations  $H_{BV}$  obtained on the same specimen have also been plotted (curve II.); the pressure used was 0.428 kg.

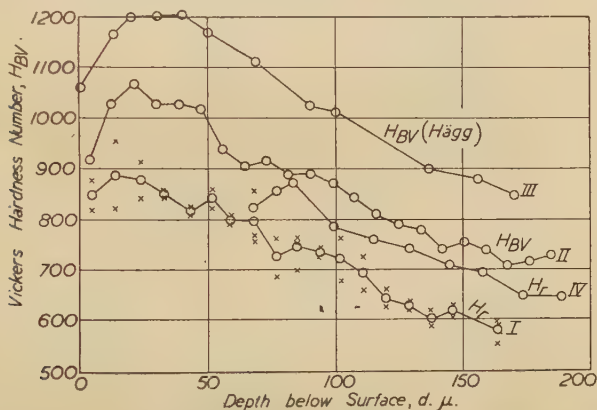


FIG. 13.—Hardness-Depth Curves. I., IV., from measured widths of sclero-gratings; II., III., Vickers determinations.

The sequences I. and II. agree comparatively well, in spite of some irregularities. On the other hand, it is obvious that the value of  $a$  should be replaced by the value  $a = 1.2 \times 10^4$ . The sclero-grating method naturally is not very suitable for absolute determinations, but it is thus obvious that *its indications may be used to obtain figures comparable with those given by, say, the Vickers method.*

Moreover, in Fig. 13, the curve obtained by Hägg on similar material, treated in the same way, has been plotted (curve III.); the pressure was 1 kg. Curves II. and III. are in rather good agreement, though the values of Hägg are considerably higher (about 150 units). This difference may be explained by assuming that the nitriding temperature here employed was slightly higher than that used by Hägg. As a matter of fact, it is well known that lower temperature gives a higher nitrogen concentration on the surface.

Finally, in Fig. 13 a shorter series of determinations made by sclero-grating has been plotted (curve IV.). In this case the pressure, roughly 2 g., was lower than in the former case (roughly 3 g.). It gave a smaller ruling width and consequently a higher  $\bar{H}$ , value (the same constant,  $10^4$ , being used). Series IV. shows that comparable results may be obtained by measuring the sclero-grating lines.

*Reproducibility.*—Before using the Vickers method definitely, it was further of interest to check the reproducibility obtained.

In Fig. 14, two series of determinations obtained on another chromium-aluminium steel, nitrated for 48 hr. at  $520\text{--}530^\circ\text{C}$ ., have been plotted. The pressure used on the Vickers point was 1.142 kg. The two series I. and II. were made at an interval of

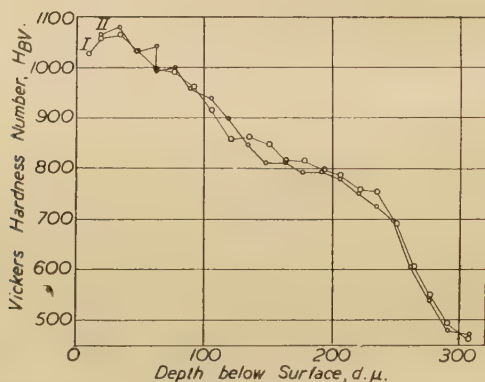


FIG. 14.—Hardness-Depth Observations proving the good reproducibility of the Vickers method.

about four days on adjacent points (distant some millimetres apart). It will be seen that they agree rather well. Thus the reproducibility is good. Both series show a rapid bending off commencing at  $d = 220\ \mu$ .

*Bending-off of the Vickers Curve.*—Concerning the above-mentioned bending-off of the Vickers curve at about  $d = 220\ \mu$ , the most feasible explanation seemed to be that this deflection might be due to the fact that at this depth the remaining thickness of the nitrated layer is too slight to carry the same pressure of the diamond pyramid. Hence in the first place an endeavour was made to investigate the situation of the point of deviation at varying pressures.

The following pressures were used for the series of Fig. 15, (a) and (b): 0.190 kg. (series I.), 0.428 kg. (II.), 0.920 kg. (III., repeated on the lower part of the figure), 1.954 kg. (IV.), 5.000 kg. (V.). On the whole, the individual series are in fairly good harmony



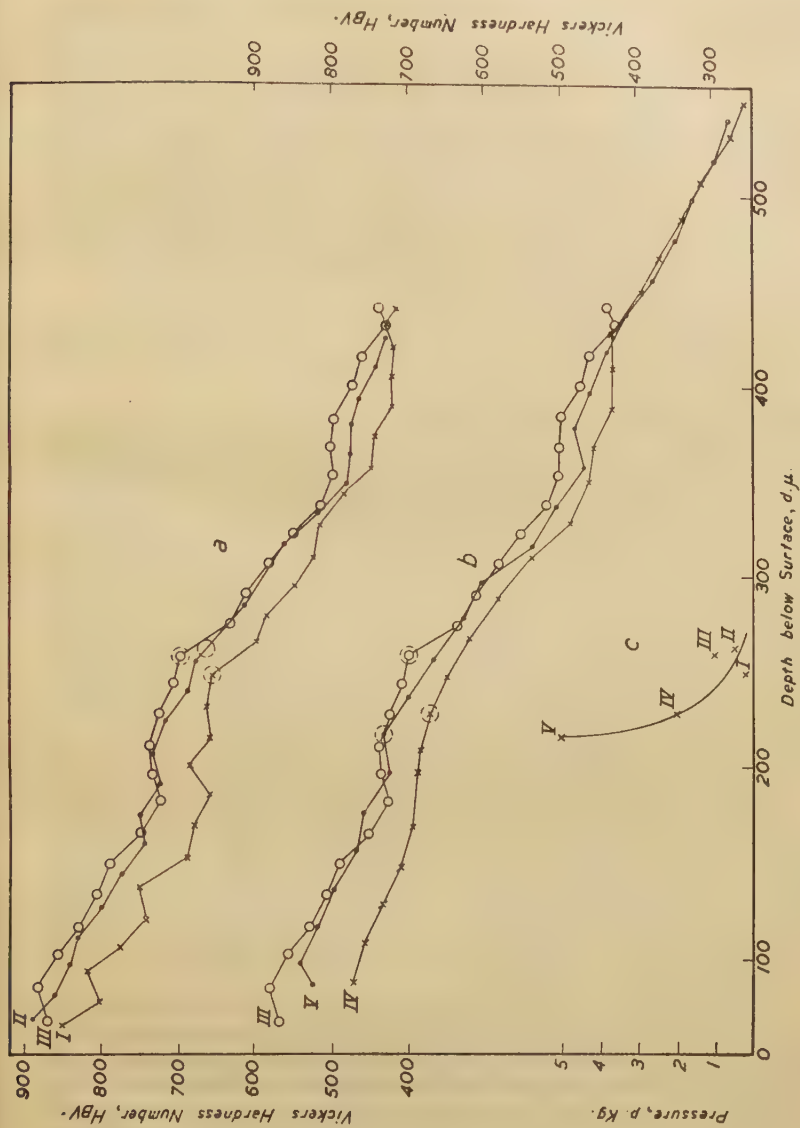


Fig. 15.—(a), (b) Hardness Determinations obtained with the Vickers Method. (c) Lowering of the Bending-off Point with Increasing Pressure.

in spite of some deviations, which hardly allow of any immediate conclusions.

For a better orientation the approximate position of the point of commencement of deviation for the series I. to V. has been evaluated. These values are given as abscissæ in Fig. 15 (c), where the pressure used constitutes the ordinate. Even if due account is taken of the rather uncertain character of the points plotted, it appears to be undeniable that *the deviation point is displaced to the left at increasing pressure*. This behaviour is to be expected, on the hypothesis that the deviation is due to *a lack of thickness in the remaining underlying nitrided layer*—a conclusion which seems to be quite natural.

A final decision on this question, of course, is difficult, considerable error in the evaluated depth being unavoidable, in spite of the care taken in locating the taper surface.

(4) *Investigation of Crack Formation in the Nitride Case on Continued Nitriding.*

Even when the nitrided surface was originally very smooth, it was found after nitriding for 48 hr. that the surface contained noticeable irregularities, though without showing any crack formation. However, after a nitriding continued during 168 hr., the surface exhibited a phenomenon, at first inexplicable, in that semi-elliptical cracks appeared, some being rather small and even (Fig. 102; ultropak illumination) and others being considerably raised above the surface. Thus, in Fig. 103 there is a "tongue" (with an elevation of up to  $15\ \mu$ ). At numerous other places there were rounded, generally slightly elongated elevations, up to  $4\ \mu$  high, having the form of blisters; at some places certain semi-elliptical pits were observed (Fig. 104).

This phenomenon must be considered to be due to a blister formation in the nitrided layer, or more correctly below an outer part of the nitrided case which is especially impermeable to gas. It is generally admitted that the ammonia diffuses as such into the steel. Thereby hydrogen is liberated and can only diffuse back to the surface. If, then, the surface layer is less permeable to the hydrogen, a high pressure may be generated, giving a local tendency to blister formation.

The mechanism of the cracking concerned may be elucidated in the following way. In Fig. 16, *a* represents an outer nitrided case, permeable to ammonia but supposed to be less permeable to the hydrogen formed (and also to the methane or steam which may possibly be formed). In consequence, the gas may concentrate locally so that weak blisters are formed. Owing to the extreme brittleness of the surface layer, the high gas pressure generated will easily cause oblique cracking on the one side along the boundaries of the blister. When the gas pressure forces off the layer near this crack, another—more or less rectilinear—crack must be formed

near the centre of the blister, as indicated at (*b*) in Fig. 16. As long as the fragment in the surface layer remains in the position

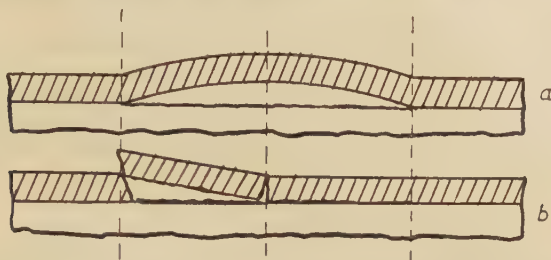


FIG. 16.—Diagram Illustrating the Cracking taking place in Blisters on a Nitrided Surface.

indicated at *b*, the appearance will resemble Fig. 103. If, on the other hand, it is thrown off (say, by an explosive gas expansion) a pit must be formed, and it will look like Fig. 104.

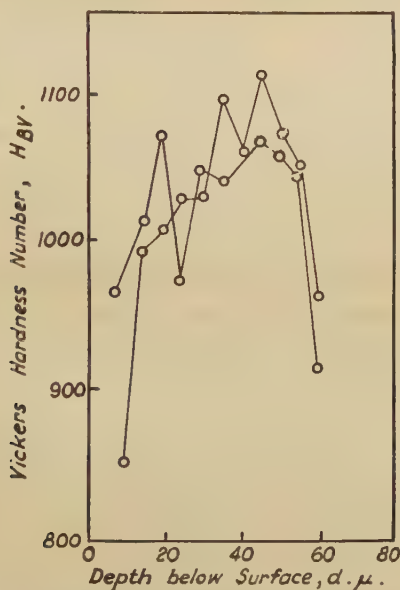


FIG. 17.—Hardness-Depth Curves near the Nitrided Surface, showing considerable variation.

As a rule, that part of the brittle surface which is situated on the other side of the central crack will remain undisturbed, the gas having found a way of escape. In some cases, however, it was

found that the blister had opened itself by the opening of the central crack.

It is not possible to say whether the phenomenon occurs with short nitriding. It does, however, appear to be the case.\*

It might be expected that this cracking would cause an obvious heterogeneity in the case. This appears to be shown by two series of Vickers observations, made just below the surface at two adjacent spots. The result is given in Fig. 17. The variations here are considerably greater than those found elsewhere.

### III.—SOME OBSERVATIONS ON LEAD CUTTING.

It has been shown above that on ruling a grating on a polished metal surface, using a sharp point, the grain structure of the metal

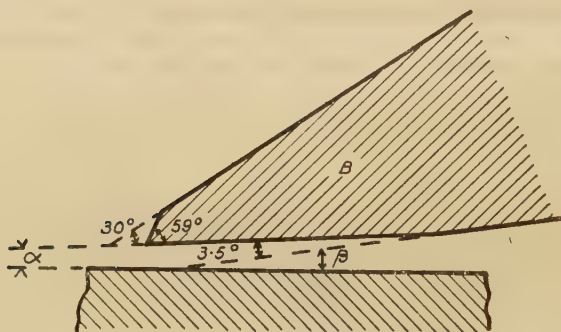


FIG. 18.—Diagram showing the Angle of the Knife Used.

may appear as though it had been etched. It was natural to question whether the same might occur when a *sharp knife edge passes over a metal surface*. The knife edge of course might be said to be a *laterally extended point*.

A small hand-driven chipper of French make ("Rapide-Lime") was available—very useful, though not possessing the same rigidity as a large microtome (Fig. 105). Great care was used in grinding, setting and polishing the knives produced for the purpose (*cf.* p. 361 P).

For the knives, various materials were tried, including Seco hard metal, and also different shapes with various cutting angles. The best for the purpose was found to be a knife (width 22 mm., length 43 mm., greatest thickness 9 mm.) made of a high-carbon steel especially free from non-metallic inclusions and with angles as indicated in Fig. 18; here  $\alpha$  is the free-cutting angle. As a

\* *Cf.* the "porous structure or raised blisters" briefly described by Sergeson.<sup>(18)</sup> The phenomenon seems to have been ascribed to the presence of oxygen in the hydrogen, though no detailed explanation has been given.



criterion of the angle adjustment the angle  $\beta$  was used ( $\alpha = \beta - 3.5^\circ$ ). The edge of the knife formed in the horizontal plane a constant angle  $\gamma = 75^\circ$ .

In order to be able to adjust the cutting depth with precision, the vertical screw of the chipper was provided with a 20-cm. arm, traversing a paper scale (1 cm. represented 0.01 mm.). This improvised device is to be seen in Fig. 105.

Much better results were obtained in oil, of which several qualities were tested, than in air. A motor fuel oil from Messrs. Wahlén and Block, Stockholm, was selected as the best. Carbon tetrachloride proved quite good, but petroleum was poor.

The material tested was a pure lead (Kahlbaum). This was moulded into square prisms ( $20 \times 20 \times$  about 200 mm.), and sawn into cubes. Zinc and copper were also experimented with, but for this purpose the rigidity of the chipper was insufficient.

It was found, at least for a definite cutting depth, that the *coarse grain structure of the lead appeared remarkably well* (see Fig. 106). It is true that the knife, without exception, caused certain longitudinal scratches (Fig. 107; same area as in Fig. 106), but no difficulty was experienced in adjusting the illumination so that these disappeared (as in Fig. 106). The scratches were caused not only by the remaining very slight unevennesses of the edge, but particularly by the adhesion of the lead, which occurs in spite of the presence of the oil. On account of this the edge had to be cleaned after each cutting, using a piece of wood.

Several series were devoted to the analysis of the most appropriate cutting depth. In Fig. 108 (a) a structure obtained at a cutting depth of 0.020 mm. is reproduced. In Fig. 108 (b) the cutting depth was about 0.050 mm. This shows much more clearly the character of the different grains. The latter cutting depth was that generally used.

It is obvious that the knife has a certain effect of tearing on the material; this effect must be of a certain magnitude in order to reveal the inner structure of the grains. In the same way as in planing wood, the properties of the planed surface, even with lead, are decidedly dependent on the cutting direction. In order to demonstrate this, the same surface as that used above was cut in the opposite direction (Fig. 108 (c)); on several grains there is a typical difference, obviously due to the orientation of the "splitting" direction in the lead crystals.

The fact that the effect presupposes a tearing action on the metal is evidenced by the circumstance that no visible grain structure besides the scratches appears when the cutting surface is parallel to the surface cut (Fig. 108 (d)).

Ever since Lucas<sup>(27)</sup> first made tests on the cutting of soft metals, it seems that the cutting direction has always been parallel to the lower cutting surface, for otherwise the grain structure would probably have been observed earlier.

Several series of tests were made with varying angle  $\alpha$ . Such a series is reproduced in Fig. 109. The different  $\alpha$  values ( $0-9^\circ$ ) are indicated below each specimen. In order to obtain the clearest structure a free-cutting angle  $\alpha = 4.5-6.5^\circ$  is preferable. At  $\alpha = 0.5^\circ$ , the structure nearly disappears.

The influence of the speed could not be ascertained, as the hand-driven chipper only permitted of small speed variations.

It was considered of interest to decide how far the characteristic appearance of the grain depended upon the surface constitution or on the mode of illumination. Photographs were therefore made of the same specimen, with the oblique illumination falling in opposite directions. The result is given in Fig. 110, (a) and (b); it will be observed that the direction of the light exercised but little effect.

On the other hand, when the same specimen was cut in the opposite direction but the direction of illumination was the same as in Fig. 110 (b), quite another aspect was obtained, as shown in Fig. 110 (c).

Several interesting observations were made on the surface cut in this way (using a free angle of  $4.5-6.5^\circ$ ). Thus, the large central grain in Fig. 106 at a magnification of 100 diameters had a certain striped surface (similar to that of pearlite), as shown in Fig. 111. The edge was roughly parallel to the lamellar direction—varying, however, within about  $\pm 8^\circ$ .

The dark spot in the middle of the light grain mentioned proved at a higher magnification to be an inclusion very sharply-defined from the striped area around it (Fig. 112). When etched, the surface cut showed in an unexpected way some remarkable details. Thus, a surface, of which Fig. 113 shows the appearance when first cut, after etching in acetic acid and hydrogen peroxide gave the *cellular appearance* illustrated in Fig. 114. On another surface (obviously orientated in a different way), etching produced a rather coarse structure with the still more variable appearance shown in Fig. 115.

It is natural to suppose that this structure is primarily caused by impurities. But as the metal was "pure" lead from Kahlbaum—though not *purissimum*—it is obvious that the impurities must be extremely low. The remelting, however, was done in an iron crucible, using a mould of brass; hence, there is a possibility that it was contaminated by iron, copper and zinc.

An analysis, made by R. Treje, gave the following figures, using a quantity of 100 g. of lead:

Iron.	%	.	.	.	0.00081, 0.00088, 0.00086; average 0.00085
Copper.	%	.	.	.	0.00262
Zinc.	%	.	.	.	0.00022

In addition, traces of arsenic, bismuth, antimony and tin were found.

Thus, the impurity contents found are actually very low. In order to be able to exert considerable influence on the micro-

structure, it is natural to suppose that the impurity is able to form a compound or phase very rich in lead. Otherwise, the amount of the foreign phase must be extremely small.

Now, copper and zinc do not fulfil this condition—which, of course, need not be exactly met; no lead-rich phase has so far been observed. As for iron, a lead-rich compound  $\text{Pb}_2\text{Fe}$  (88.1% lead) has recently been described by Daniels.<sup>(28)</sup> This compound is light in colour and resembles (according to his Fig. 2) some sharply bounded, white inclusions as seen in Fig. 115, which might be identical with the inclusion reproduced in Fig. 112. The fact that this compound had not been observed earlier might be related to the observation of Daniels that it is formed only slowly (molten lead reacting with  $\text{FeCl}_3$ ). Now, if this compound actually is present, it must form with lead a eutectic having an extremely low iron content—though nothing is known definitely. Consequently, it does not appear to be entirely excluded that the small amount of iron present may be able to cause some visible structure, in spite of the iron content being less than 0.00085%.

As for copper—which occurs in a quantity three times as great—no lead-rich phase is known, but, on the other hand, it has been established by Heycock and Neville<sup>(29)</sup> that there is a eutectic point—situated about one degree below the melting point of pure lead (327° C.)—corresponding to a content of about 0.06% of copper.

Similarly with regard to zinc—also found to occur here—no lead-rich, intermediate phase has been observed, but Hodge and Heyer<sup>(30)</sup> recently found the existence of a eutectic point (at 318.2° C.) corresponding to a small content of zinc estimated to be 0.05–0.06%.

These eutectic contents—though small in comparison with all better-known eutectic contents—are, however, rather high in comparison with the impurity contents found to exist in the lead used.

The question then will be whether or not a co-activity (joint action) of different impurities might occur. This by no means seems improbable. On cooling, a higher concentration of the impurities must necessarily occur at distinct, roughly equidistant points. The concentration corresponding to the limit of solubility (so that precipitation might take place) will naturally occur at equidistant points, the distance between which will be greater the purer the metal.

Now it seems quite natural that this periodical concentration might be the same for the different impurities—which thus may be said to be co-active.

If this be accepted, the explanation of the phenomenon observed will somewhat be as follows :

(1) The cutting of the metal, under the conditions described above, is extremely sensitive to very small internal heterogeneities; small though they may be, they may cause the

appearance of a characteristic, uneven surface—especially on cutting a grain in certain directions.

(2) On etching, local elements will appear owing to these concentration differences and also owing to varying cold-working resulting from the tearing of the metal. This will give the appearance that the heterogeneities are much more bulky than is actually the case.

Hence, the phenomenon observed would be due to the combination of a mechanical effect, to some extent altering the material, and a *chemical etching*, a combination which might represent a high sensitivity.\*

The above seems to suggest interesting metallographic possibilities, but before definite statements can be made further researches are necessary.

With regard to the primary question, whether any hardness increase in the actual grain boundaries can be observed, no such excess of hardness has been noticed with the lead cutting, which was, of course, scarcely to be expected on account of the purity of the lead used.

Fig. 116 illustrates the appearance of a cut surface produced on the lead specimen containing a small amount of intentionally added iron, mentioned on p. 360 P; it reveals a striking difference in surface character between two adjacent grains, of which the lower one has probably been cut in a direction opposite to its "splitting" direction. No special hardness increase, however, can be seen in the grain boundary concerned.

The structure produced by cutting—not previously described, so far as the author is aware—seems to merit a much closer study; this, however, was outside the scope of the present investigation.

#### IV.—DISCUSSION OF THE CONDITIONS FOR SENSITIVITY OF THE SCLERO-GRATING METHOD.

It has been seen in the foregoing that it was possible to establish the existence of increased hardness along a grain boundary (for aluminium and iron) after annealing in nitrogen, while after ordinary annealing in air no such hardness increase could be seen. It may by no means be concluded that the phenomenon might not

\* Quite recently, J. N. Greenwood and H. W. Worner (*Monthly Journal of the Institute of Metals*, 1939, vol. 6, Oct., p. 513) have published micro-structures similar to those observed above in lead containing 0.05% of tellurium or even as little as 0.006% of selenium. These structures do not appear on etching lightly, but are revealed after a deep etching. Thus, a prolonged attack seems to give the same result as the above combination of cutting and light etching.

The occurrence of banded or cellular structures (similar to Figs. 111 and 114) in single crystals of fairly pure metals (zinc, copper) has been well described by M. Smialowski (*Zeitschrift für Metallkunde*, 1937, vol. 29, p. 133), who gives a valuable recent bibliography on the matter.



possibly be found to exist even in the latter case, provided that the sensitivity of the sclero-grating method were further increased. This problem, therefore, is certainly of importance, and a discussion may be considered advisable.

When it is a question of obtaining maximum sensitivity for small local differences in hardness, according to the experience gained the following factors may be considered to be decisive :

- (I.) Suitable shape of the point.
- (II.) Weakest pressure practicable.
- (III.) Close ruling.

Concerning (I.), the shape of the point, two possibilities are to be considered :

- (1) The point is geometrically defined.
- (2) The point has an irregular configuration.

In the former case, apparently only two possibilities are to be taken into account :

- (a) The line ruled is limited by two planes (containing the line) each forming an angle  $\alpha$  with the normal to the surface.
- (b) The ruled line may be limited by a cylindrical surface.

*Factor I.(1a).*—Regarding the first case, it must be said that the greater the value of  $\alpha$ , the greater will be the difference in width that may arise under given conditions for a given "hardness moment" (the product of the hardness and the extension in the ruling direction). Thus  $\alpha$  must itself be chosen as large as possible. Of course,  $\alpha$  must be limited in order to avoid difficulty of observation due to vagueness in the edge of the ruling. On the other hand, in order to react for a small hardness moment, the point should have as small an extension in the ruling direction as possible (or a small angle  $\beta$  in the ruling direction).

According to this reasoning, a rational shape for the point would be a three-sided pyramid, in which the "rear" plane is nearly vertical and the other two planes cut each other symmetrically along a line forming a *small* angle  $\beta$  with the rear plane; these two planes cut the rear plane to form a wide angle  $2\alpha$ .

Such a shape, however—rather similar to the shape of a certain Seco point tried above—has the great inconvenience that it may wear considerably. On this account its use is almost out of the question.

An increase of the resistance to wear by enlarging  $\beta$  would, of course, lower the sensitivity for a given hardness moment.

*Factor I.(1b).*—In order to obtain high symmetry when using a geometrically defined point, recourse must probably be had to a spherical shape of point. In order to obtain a considerable difference in width on a small indentation depth one must use—just as in the Brinell test—an impression angle as small as will allow of

clear observation. It is easy to conclude that the spherical surface of the point should possess a radius of curvature of the same magnitude as the width of the rulings, *i.e.*, 2–4  $\mu$ .

The production of such a spherical surface suitable for the purpose seems, however, to entail extremely great difficulties—which, of course, would be still greater if the curvature, according to what has just been explained, were rendered smaller in the ruling direction, *i.e.*, the sphere were replaced by an ellipsoid of rotation.

*Factor I.(2).*—In the light of the foregoing, the prospects of obtaining very high sensitivity appear to be reduced to the use of an irregular point, at a special critical pressure, characterised by a secondary peak which at slight variations in the indentation depth may or may not scratch. This throws one back on the method which in this research has frequently given the best results, namely, that making use of the action of a secondary peak. It has been found that by making a suitable microscopic examination of the point certain indications may be obtained, though the functioning of the point will depend to a large extent on chance.

*Factor II.*—With regard to the weakest pressure employable, this, of course, is limited by the necessity of being able to study the rulings obtained at the magnification of the microscope available (about 1500 diameters). Thus, no considerable lowering of the pressure appears possible (below that used here, down to 0.05 g.).

*Factor III.*—Concerning the closeness of the ruling, little more is to be attained when using the type of dividing machine which has been at the author's disposal. It appears to be not improbable that the special machines used for the ruling of optical gratings might be able to give appreciably increased sensitivity by decreasing the space between the lines. This would make a high quality of the surface essential.

## V.—SUMMARY.

### A.—The Sclero-grating Method.

(1) The method introduced by Benedicks and Mets for the study of hardness, consisting in ruling a fine grating on the surface of the metal—here called the “sclero-grating” method—has been progressively improved and refined.

(2) The essential feature is that the point-bearing or ruling organ is now of very small mass and has high lateral stability as well as freedom from friction. The smallest ruling distance has been brought down to about 2  $\mu$ . The lowest pressure used was 0.05 g.

(3) For the ruling points different materials and different shapes were tried. For the detection of hardness difference, however, no strictly geometrical shape of the point is necessary; particularly high sensitivity is frequently achieved through the action of a secondary point. A detailed discussion is presented (*see* Section IV.).

(4) The ruling speed should not exceed a maximum value, depending on the pressure, the hardness of the material to be ruled and the presence of oil.

(5) In a detailed examination of a diamond point, good agreement was reached between the rulings obtained and the configuration of the point, especially the shapes of its highest peaks, which, by a suitable system of illumination, were successfully photographed at a high magnification (Figs. 51 to 53).

(6) In order to check the sensitivity obtained with the sclero-grating method, use was made of brass containing a thin inlaid nickel layer. It was found that the difference in ruling hardness in adjacent grains (of iron) was large enough to develop the grain structure—roughly like that produced by etching (*see* Fig. 26).

The sensitivity is particularly good at low pressures combined with a small ruling distance. The sclero-grating method reveals the cold-working occurring under individual scratches in the preliminary grinding (*see* Fig. 61).

#### B.—*The Problem concerning the Hardness of Boundaries.*

(7) The problem was as follows: It had been assumed by Benedicks and Löfquist that certain dissolved substances could be enriched molecularly in the grain boundaries of a metal, thereby hampering grain growth. If this were the case, one might expect a certain hardness increase to occur in the boundary—even in the absence of any microscopic precipitation. The aim was to investigate how far it was possible by means of the sclero-grating method to detect any such hardness increase.

(8) Numerous trials embracing different irons, lead contaminated with nickel, and aluminium contaminated with iron, which were all heat-treated in air, on the whole gave negative results.

(9) On the other hand, when the annealing was done in an atmosphere of nitrogen, in which especially hard nitrides might be formed—as aluminium nitride, which Benedicks and Löfquist have shown to be predominantly grain stabilising—the results were different. Experiments were first made with aluminium. It was found here that a sensible hardness increase did occur, even though it was not possible to observe under the microscope any precipitation in the grain boundaries (Figs. 57 and 58).

On aluminium interesting observations were made, indicating that lamellæ of  $\text{Al}_3\text{Fe}$ , on annealing, projected from the surface (Fig. 54). In the neighbourhood of blow-holes, the aluminium was found to contain portions softer than the bulk; near large  $\text{Al}_3\text{Fe}$  inclusions the metal also contained portions harder than the rest.

In sclero-gratings made on iron, grain boundaries were observed in which this method clearly revealed a greater hardness, although no precipitation could be detected under the microscope (Figs. 64 and 65). In iron, likewise, harder portions were found to exist near sulphide inclusions (*see* Fig. 66).

In large non-metallic inclusions, the presence of two phases was clearly revealed by the sclero-grating method (Fig. 23).

### C.—Detailed Study of Nitrided Layers.

(10) The sclero-grating method was finally applied to the study of the hardness of the microconstituents of the nitrided case—in regard to which earlier determinations had been exclusively concerned with the resulting or total hardness at different depths.

(11) In nitrided soft iron, the  $\alpha$  phase is very much softer than the  $\gamma'$  phase. If the phases be ranged in the order of decreasing hardness, the sequence is :  $\epsilon$ ,  $\gamma'$ ,  $\alpha$ —a sequence corresponding to the variation of the nitrogen content. This explains the curve of total hardness for nitrided soft irons, in which the hardness is found to decrease from the surface inwards.

Accidentally, a grain boundary was observed—where no  $\gamma'$  phase could be found—possessing a greater hardness than that of the adjacent grains.

(12) In nitrided chromium-vanadium steel, the  $\alpha$  phase was found throughout to be appreciably harder than in the preceding case. The hardness, however, decreased inwards, so that at a greater depth it was less than that of  $\gamma'$ ; at a certain depth the hardnesses of both phases may be the same. The  $\epsilon$  phase here has a relatively slight hardness.

Consideration of these observations provides a reasonable, though hypothetical, explanation of the curve of total hardness for the steels showing two hardness maxima (*cf.* Fig. 12).

(13) In nitrided chromium-aluminium steel, the  $\alpha$  phase proved to be of comparatively still greater hardness. The sclero-grating experiments on this material were far too few, but the impression was gained that the phases behaved in respect of hardness very much as they did in the chromium-vanadium steel.

(14) Hardness-depth curves obtained by using the sclero-grating method and measuring the widths of the rulings gave fairly good agreement with those obtained by the Vickers method.

A number of determinations made on the Vickers method indicated that the bending-off frequently occurring in the hardness curves (at greater depths) might be explained by assuming that the residual layer of the nitrided case was so thin that it gave way under the pressures generally used.

(15) A description is given of a characteristic blister formation which appeared on the continued nitriding of chromium-aluminium steel and gave rise to semicircular cracks, with or without flaking-off. This seems to give a certain insight into the mechanism of nitriding.

### D.—Cutting Experiments.

(16) In connection with the sclero-grating experiments, some tests on the cutting of a soft metal with a knife—which may be regarded as a laterally elongated point—were made.



Chiefly, pure lead (Kahlbaum) was used. It was found that the grain structure of the metal could be beautifully developed by cutting (Fig. 106), in much the same way as in etching. The main condition is that a sufficiently large free-cutting angle ( $4.5-6.5^\circ$ ) must be used—and not close contact, as has been probably used most frequently hitherto.

On the surface so prepared, a curious substructure was discovered (Figs. 111, 114 and 115), which is interpreted as being due to the presence of slight impurities. This structure—recalling certain solidification structures, but of a much coarser character—may become visible owing to the combined actions of the surface cutting and etching, both of which are extremely sensitive to heterogeneity in the metal.

#### ACKNOWLEDGMENTS.

To Professor C. Benedicks, who gave the incentive to the work and has continuously followed its progress with advice and assistance and who, in particular, has devoted a considerable amount of work in connection with the drafting of the manuscript, the author wishes to express his deep-felt thanks.

Extremely valuable aid, especially in the matter of design, has been given by the assistant engineer, Mr. P. Sederholm.

Through the instrument-maker, Mr. C. A. Andersson, also, who carried out the mechanical work on the apparatus with great skill, a number of improvements in construction have been made.

In the discussion of numerous metallurgical matters Mr. H. Löfquist, mining engineer, has been very helpful.

Mr. R. Treje, M.A., has been exceedingly kind in making a number of necessary analyses.

A considerable amount of the requisite apparatus, belonging to the Metallografiska Institut—where the investigation was carried out—was very willingly placed at the author's disposal by Mr. G. Phragmén, Fil. Lic.

Useful specimens have been made available through Professor Benedicks from A/B Svenska Aluminiumkompaniet, Stockholm, A/B Svenska Metallverken, Västerås, Fagersta Bruks A/B, Fagersta, Professor J. Czochralski, Warsaw, and Professor A. E. van Arkel, Eindhoven.

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## DISCUSSION.

In the absence of the AUTHOR, this paper was presented by Dr. C. H. DESCH, F.R.S. (Vice-President).

Dr. HUGH O'NEILL (Derby) said that the search for increased hardness at crystal boundaries went back to the days of the hunt for the intercrystalline amorphous cement. If, therefore, the author had succeeded in capturing his quarry, supporters of the cement theory would have welcomed the news for their own particular purposes. Personally, he had also experimented with scratch tests, but with the object of trying to find a case-hardening type of effect at crystal boundaries due to possible lattice transitions or lattice distortion. The quest in the present case was, however, a different one, and had important practical relationships. A hardness gradient at the boundary would be considered to support the views of Benedicks and Löfquist that the inherent grain size of steel could be ascribed to the boundary migration of impurities such as nitrides. Aluminium nitride might then be considered to have some direct influence on the inherent grain-size behaviour of steel.

The painstaking work of the author in connection with this laborious method of "mechanical etching" had unfortunately given negative results, except as regards conclusion (9) in the Summary at the end of the paper. In that case, aluminium heated in nitrogen was stated to show an increase of hardness at the boundaries according to Figs. 57 and 58. Furthermore, the "mechanical etching" of iron annealed in nitrogen was stated to give grain boundaries which "clearly reveal a greater hardness." That conclusion was based on Figs. 64 and 65.

Even allowing for the great difficulties of the experimental work, Figs. 57 and 64 were rather unconvincing, and the number of constrictions in the ruled scratches was so great that it hardly seemed justifiable to ascribe any one of them to a hard grain boundary. Three independent observers had been asked to draw in a boundary network for Fig. 64 by connecting constrictions in the scratches, and the results obtained differed very widely. It must be admitted, however, that in almost all cases the line *aa* of Fig. 65 was confirmed, and perhaps the author would publish the etched structure corresponding to Fig. 64, so that the location of the boundaries could be seen exactly. Even if boundary hardening could be conclusively demonstrated, however, it would be necessary to eliminate not only the possibilities of amorphous-cement and lattice-transition effects but also the possibility of preferential hardening at the boundaries due to preparation by polishing. Personally, he had shown that in cold-worked iron there was

preferential hardening as the boundaries were approached,<sup>1</sup> and the same effect might be produced by polishing.

Although this part of the research had not given convincing results, he was very pleased to see the evidence reported on pp. 372 P and 397 P that scratch testing would reveal the presence of cold-worked metal, produced in the present case by preliminary grinding operations. It was a matter of dispute whether scratch tests did react in that way. Tammann had repeatedly reported that a scratch made on cold-worked metal had the same width as one made on the same metal annealed, but personally he had shown that if the scratch was made with a hemispherical diamond point this was certainly untrue, and studies of cold-working could be made with accuracy when using such a scratch test. The author had now confirmed this view, using sharp-pointed scratching tools, and it remained to be shown why Tammann's work had reported an opposite effect.

The substructures "discovered" in grains of lead, and illustrated in Figs. 111, 114 and 115, were not new. Adcock<sup>2</sup> showed their presence in pure silver, and other workers had found them in lead, antimony, zinc and tin. Probably they were due to slight impurities, as the author suggested, but attention might have to be paid to them in connection with the Quincke foam-cell hypothesis regarding solidification.

Dr. BRUCE CHALMERS (London) said that on reading the paper one was first struck by the beauty of the technique, and it was only after consideration that one began to wonder whether the new method gained anything in novelty of results or accuracy of interpretation. It did appear that increased hardness at crystal boundaries showed up in certain cases when the sclero-grating method was used, but one wondered whether the author's interpretation of the boundaries which he found to be hardened was correct. As this was essentially a new application of a new method, the question of its interpretation was important.

Personally, he would like to suggest some possible causes of misinterpretation of the results. He put them forward as *possible* causes and not as *probable* causes. In the first place, in one or two of the photographs shown, only a few of the probably much more numerous boundaries gave any evidence of increased hardening. That might be due not to the fact that those particular boundaries were specially enriched, and therefore specially hard, but to quite a different cause, namely, that the resistance to mechanical distortion of a crystal boundary depended, as he had shown in another connection, on the angle between the crystallographic axes of the two crystals between which the boundary was formed;

<sup>1</sup> *Iron and Steel Institute, Carnegie Scholarship Memoirs*, 1928, vol. 17, p. 109.

<sup>2</sup> *Journal of the Institute of Metals*, 1921, No. 2, p. 361.



and so it might happen that in a specimen certain of the crystal boundaries were formed between crystals with a large angle between their crystallographic axes, and there was an increased resistance to distortion and therefore resistance to crushing, whereas other boundaries might be formed between crystals having nearly the same orientation, and therefore there would be less boundary effect.

Secondly, in some work which he and Mr. Hoare had done some years ago on the levels of polished metals as determined by means of interference fringes, they had shown that where a harder constituent was present one often obtained a definitely raised portion after polishing. When the ruling point came to the edge of such an elevated or depressed region the result would be the appearance of increased or decreased hardness of a boundary owing to the point having to jump up or down from one crystal to the other.

He did not think that those points vitiated the possible application of the author's method, but those points and others did lead, he thought, to the necessity for a very careful study of the application of the method in cases which could also be examined by other methods. The author had done that in the part of the paper in which he dealt with hardness as determined by the pyramid method, where it was shown that this new method did apply and gave useful quantitative results in that particular type of application. It did not, however, establish the general usefulness of the method in other cases where there was no confirmation. The method might be found extremely useful in measuring quantitatively hardnesses of certain electrodeposits which were too thin to be measured by ordinary indentation methods or even by ordinary scratch hardness tests. Such cases did arise and had caused a great deal of trouble in the past.

Dr. C. H. DESCH, F.R.S. (Vice-President, London), remarked that it might be worth mentioning that the method of revealing the structure of an alloy by a very fine machining tool passing over it had been used by the late Sir John Dewrance in the study of bronze castings. Sir John showed to the Institute of Metals a very fine album of photographs prepared in that way. Although he (Dr. Desch) and Mr. Shaw Scott had made a search, they could not find any record of them, but in Sir John's Presidential Address to the Institute of Metals in 1927 one of the plates had been prepared in that way. It could hardly be distinguished from an etched specimen except by looking at it with a lens, when it would be found that it was actually prepared by machining. There was sufficient difference in hardness between the different constituents for the tool to jump a little at each one, and the structure was revealed very beautifully.

Fig. 114, showing a fine network, as Dr. O'Neill pointed out, was very familiar. That kind of structure was obtained with many metals; Professor Mason in America in 1935 found a structure of

that kind in tin obtained as chemically pure, and proved that it was due to impurities. Professor Mason was able to purify the tin until that structure vanished completely, and then he could restore it by putting in 0.004% of bismuth. There was no doubt that it was due to chemical heterogeneity on a very small scale.

The author's reply had not been received at the time of going to press.

# THE MANUFACTURE OF PIG IRON IN AMERICA.<sup>1</sup>

By WILLIAM A. HAVEN (CLEVELAND, OHIO, U.S.A.).

(Figs. 10 to 32 = Plates XL. to LI.)

## ABSTRACT.

In this paper on the manufacture of pig iron in America, the author's specific purpose is to describe the designs, equipment and practices which characterise practically all modern American blast-furnaces, notwithstanding some great differences in the nature of the raw materials used in the principal producing districts.

The chief pig-iron-making districts are first reviewed briefly (Mexico, Nova Scotia, Southern or Alabama District, Rocky Mountain District, Eastern New York and Pennsylvania District, Mid-Western District), and then data on the iron ores of the Lake Superior District are presented (chemical qualities, iron content, beneficiation, reducibility, physical characteristics, output). Next, a description of the transportation of Lake ores (distances and charges, storage facilities, Lake carriers) is followed by an account of Appalachian coking coals and coke (river transportation, transport costs, mining methods, quality of coal, coke-ovens and the blast-furnace plant, coke quality). Attention is then directed to blast-furnace plant and equipment, and detailed consideration is given to raw-material unloading facilities, raw-materials storage, stock-house bins, bottom and top charging equipment, the stack, the cooling, the lining and dimensions of blast-furnaces, casting facilities, metal and slag handling, power plants and blowers, hot-blast stoves, gas-cleaning equipment, and sintering and sintering plant. Finally there is a short section on blast-furnace practice in America.

Numerous illustrations and Tables of data are included.

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SOME of the statistics and data presented in this paper were prepared especially for the benefit of the Members of the Iron and Steel Institute who were to have visited America for the first time in the fall of 1938. Other information that is believed to be of interest to blast-furnace operators generally has now been added. A specific purpose of the author has been to describe the designs, equipment and practices which characterise practically all modern American furnaces, notwithstanding some great differences in the nature of the raw materials that are used in the principal producing districts. These districts, with one exception, are located along an imaginary line which extends from Monterey, Mexico, to Sydney, Nova Scotia, a distance of about 2700 miles.

An aerial photograph of Gary Works, which includes the world's largest pig-iron-producing plant, with twelve modern blast-furnaces,

<sup>1</sup> Received September 5, 1939.

is reproduced in Fig. 12. This shows a typical arrangement for lake-front plant, with docks, fast unloaders, reserve stock piles for ore and limestone, and stocking and reclaiming bridges.

#### PRINCIPAL PRODUCING DISTRICTS.

##### *Mexico.*

A single stack at Monterey, of 300 tons daily capacity, is the only pig-iron-producing blast-furnace in Mexico. This plant owes its existence to the fact that the southernmost exploited field of coking coal on the Continent, which is at Sabinas, near the United States border on the Rio Grande, is only about 150 miles from Monterey. Furnace coke of good physical and chemical quality is produced from Sabinas coal in by-product ovens located at the mines.

Iron ore is plentiful, and that used at Monterey is from a deposit in the nearby State of Durango. This ore deposit is said to have been discovered by followers of Cortez, to whom it was reported by Indians to be a mountain of silver. Actually, it does form part of a small mountain, from which the ore is easily recovered in open workings. The ore is a hard, high-grade hematite, and the pig iron produced from it is mostly used as molten metal in an adjacent basic open-hearth steel plant. There is a steel plant in Mexico City, but it depends for its raw materials almost entirely upon local supplies of steel scrap.

##### *Nova Scotia.*

In Nova Scotia, the ore used is exclusively Wabana from Newfoundland, a dense, hard hematite, containing about 52% of iron with 12-14% of silica, but no lime. It is a near-basic-Bessemer grade containing about 0.90% of phosphorus, but the Bessemer process of steelmaking, after a brief trial at Sydney, was given up and the basic open-hearth method, using tilting furnaces much along the lines so generally used for converting high-phosphorus pig iron in England, was adopted.

The Nova Scotia and the English Cumberland districts have one thing in common, in that coal at both places is mined from beneath the sea. The Nova Scotia coal is too high in volatiles to be of good quality for coking alone in by-product ovens and does not lend itself readily to washing, so that the resultant coke is softer and higher in both ash and sulphur than coke made at Workington. The sulphur at about 1.75% is detrimental to comfortable blast-furnace practice, but would be more so were it not for the fact that the raw materials of this district as a whole produce a slag volume of about 1800 lb. per ton of pig. The largest of the Sydney furnaces, a stack of 18 ft. 3 in.  $\times$  89 ft. in size, produces over 500 tons daily with less than a ton of coke per ton of pig iron on a straight ore burden.



*Southern or Alabama District.*

Somewhat similar conditions to those at Sydney prevail in the Birmingham, Alabama, district, where the principal ores are also hard, high-phosphorus hematites. These ores are of much lower grade than the Wabana, as they contain only about 38% of iron, but on the other hand they are virtually self-fluxing, so that the fuel requirements per ton of pig iron are about the same in both cases.

In the latter respect, the practice in both districts has been greatly improved in recent years by crushing the ore to smaller sizes. Crushing to — 4-in. ring is now common and the best practice has been with still smaller sizes. It seems likely that the optimum in both districts will be found between 1 in. and 2 in. maximum. Coke consumption of less than ton-per-ton has also been achieved in Birmingham, whereas, with larger sized ore, from 2500 to 2700 lb. was the rule.

*Rocky Mountain District.*

The Provo district in the Rocky Mountain State of Utah is distinguished for having pioneered the possibilities in the direction of crushing, grading the ore by size and charging the various sizes separately. The ore used is hard hematite containing about 53% of iron, and the coke is very soft, so that the early operations at this plant were difficult. Credit is mostly given to the procedure of crushing and grading the ore for reducing the coke consumption from 2500 lb. to about 1750 lb. and also greatly increasing the furnace output.

*Eastern New York and Pennsylvania District.*

Still another pig-iron-producing district in America, about the practice of which very little may be known in England, is that of the magnetite ores in Eastern New York, Eastern Pennsylvania and New Jersey. Although remote from soft coal supplies, the plants of this district have finally been put on what appears to be a sound economic basis by improvements in methods of ore dressing and in sintering of the fine heavy concentrates.

The question often raised as to the limit to which sinter can be used in the furnace burden is answered at some plants in this district which are actually using 100% of sinter with complete success. Coke practice of less than 1500 lb. per ton has been reported. The sinter is richer and of better structure than that made from flue dust or from a mixture of flue dust and soft ores.

*Mid-Western District.*

However, by far the greater part of American pig iron—about 80% of the total in a normal year—is manufactured in a region which depends for its raw materials upon the Central Appalachian

coal fields and the iron ore deposits of Northern Michigan, Wisconsin and Minnesota. Herein are found not only the great producing centres of Pittsburgh and Chicago, with their super-plants of Homestead and Gary, but also the districts of Cleveland, Buffalo, Detroit and the Ohio River Valley, in each of which are plants the annual productive capacity of which is measured in millions of tons. The region may be defined as that encircled by the Allegheny Mountains, the Great Lakes, and by the Ohio and the Mississippi Rivers. In this mid-western area have been felt the full effects of the unusual combination of economic, geographical and metallurgical conditions which American methods of pig-iron manufacture and the American type of blast-furnace have been developed to meet.

Some of the plants in this region are situated very close either to the middle Appalachian coal fields or to the Lake Superior ore deposits. At the one extremity will be found Johnstown, Pennsylvania, where the Cambria Plant of the Bethlehem Steel Company is located, literally on top of the coal, and at the other, a thousand miles away, Duluth, which is, figuratively at least, on top of the ore. The freight charges on coal at Johnstown are negligible, but on ore amount to approximately \$6.00 per ton of pig iron, while at Duluth freight charges on ore are only \$1.75 but on the coal about \$4.25 per ton of pig iron. The transportation charges on ore and coal combined, therefore, are about the same in both cases.

Plants between these points are situated alongside or near water-courses, principally the Ohio River and its tributaries or one or another of the Great Lakes, from which are derived relatively cheap transportation for either ore or coal, or for both. These geographical features do not completely determine the desirability of the location for pig-iron manufacture, since the cost and availability of scrap suitable for blast-furnace use and the proximity of the producing plants to the markets for pig iron and for blast-furnace by-products are other determining factors. But since all the plants of the Mid-West have had the same or very similar raw materials, the constructional features and manufacturing methods of the entire industry in this district have been largely determined by the nature of these materials and the problems incident to their mining, beneficiating, transporting and smelting.

#### THE IRON ORES OF THE LAKE SUPERIOR DISTRICT.

A map showing the situation of iron ore deposits in the United States is given in Fig. 1. A portion of a large open-pit iron ore mine on the Mesabi Range is illustrated in Fig. 13, while Fig. 14 shows the application of transportation by lorry to open-pit mining.

The principal iron ore reserves in North America are listed in Table I., and some statistics and analyses of American iron ores

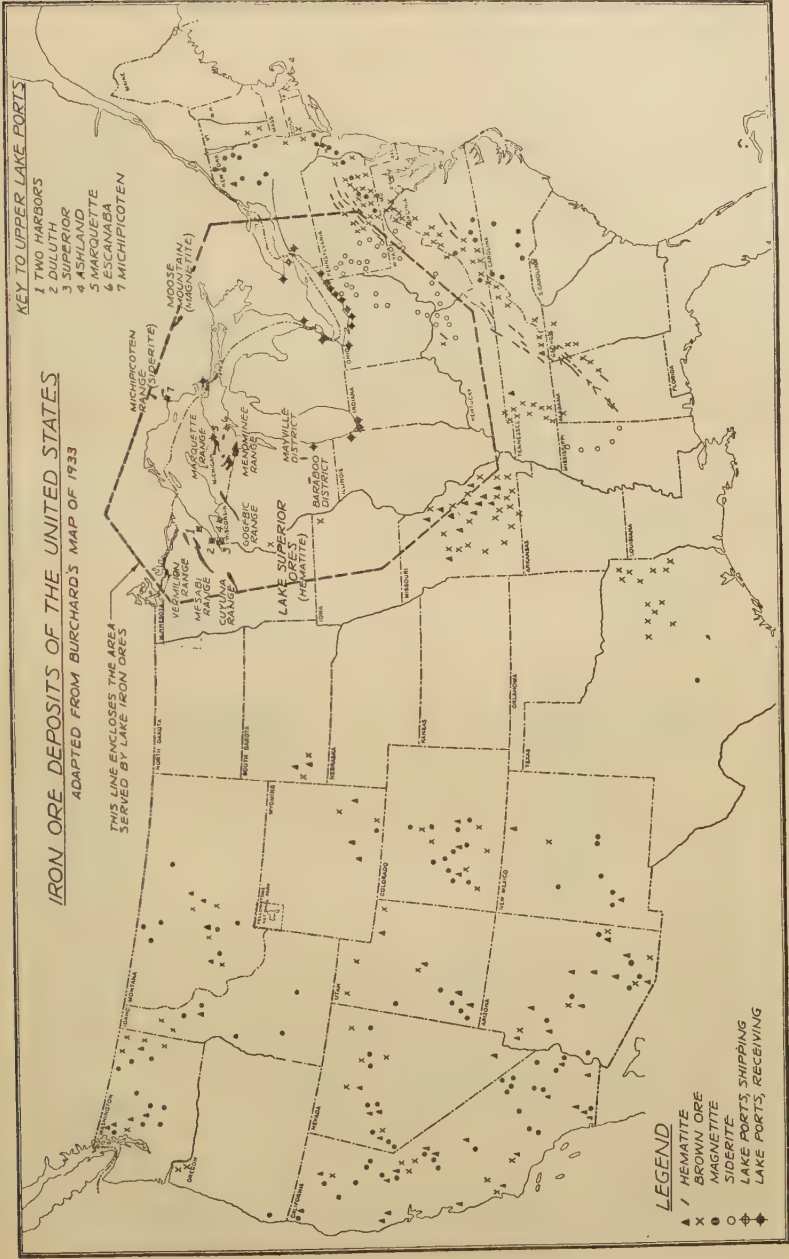


Fig. 1.—Iron Ore Deposits of the United States. (Adapted from Burchard's Map of 1933.)

are given in Tables II. and III. Table IV. contains typical screen analyses of Lake Superior iron ores.

### *Chemical Qualities.*

From a chemical-analysis standpoint the Lake Superior ore fields have provided a sufficient variety of ore for the manufacture of all the principal foundry and steelmaking grades of pig iron, but not ferro-alloys. A few mines in the Cuyuna range can supply ores with manganese contents of from 5% to 10% and two of them with more than 15% of manganese, but the shipments of these are relatively small. These are used only for the regulation of the manganese content in the ordinary grades of pig iron. There is some manganese ore produced in Southern and Western States, but American requirements of these materials have in ordinary times been imported from Russia, India, Brazil, the Gold Coast and Cuba.

TABLE I.—*Principal Reserves of Iron Ore in North America.*

<i>United States</i>	Net Tons.
Total reserves now commercially available, inferior ores or isolated deposits not included . . . . .	4,061,459,000
Lake Superior :	
Minnesota . . . . .	1,250,000,000
Michigan . . . . .	150,000,000
Wisconsin . . . . .	6,000,000
Total . . . . .	1,406,000,000
Southern :	
Scattered small deposits . . . . .	500,000,000
Birmingham District . . . . .	1,500,000,000
Tennessee River Basin . . . . .	119,959,000
Total . . . . .	2,119,959,000
Eastern : Cornwall, Pa., and Adirondack Region . . . . .	147,000,000
Iowa . . . . .	10,000,000
Missouri : Iron Mountain District . . . . .	1,000,000
Texas . . . . .	200,000,000
Wyoming . . . . .	11,000,000
Colorado . . . . .	5,000,000
New Mexico . . . . .	15,000,000
Utah : Iron Spring District . . . . .	40,000,000
Arizona and Nevada . . . . .	30 deposits
Washington . . . . .	5,000,000
Oregon . . . . .	1,500,000
California . . . . .	100,000,000
Low-grade magnetites that could be concentrated :	
Eastern New York, Pennsylvania and New Jersey . . . . .	2,500,000,000
East Mesabi . . . . .	5,000,000,000
Canada . . . . .	400,000,000
Newfoundland : Wabana . . . . .	3,500,000,000
Mexico . . . . .	2,000,000,000
Central America . . . . .	250,000,000
Cuba . . . . .	3,000,000,000



TABLE II.—*Iron Ore Statistics.*

<i>Production of Iron Ore in the United States in 1937.</i>		
State of Origin.	Production in Gross Tons.	Percentage of Total Production.
Minnesota . . . . .	48,210,000	66·80
Michigan . . . . .	12,294,000	17·04
Alabama . . . . .	6,360,000	8·81
Pennsylvania and New York . . . . .	2,625,000	3·64
Wisconsin . . . . .	1,183,000	1·64
New Jersey . . . . .	525,000	0·73
Other States . . . . .	969,000	1·34
Total . . . . .	72,166,000	100·00
Lake Superior Region . . . . .	61,687,000	85·48

<i>Shipments of Lake Iron Ores in 1937.</i>		
Range.	Gross Tons Shipped.	Percentage of Total.
Mesabi . . . . .	45,823,571	72·61
Marquette . . . . .	5,747,812	9·11
Gogebic . . . . .	5,661,270	8·97
Menominee . . . . .	2,649,062	4·20
Cuyuna . . . . .	1,775,445	2·81
Vermilion . . . . .	1,453,080	2·30
Total . . . . .	63,110,240	100·00

<i>Imports of Iron Ore by Countries of Origin, 1937.</i>		
Countries.	Gross Tons.	
Chile . . . . .	1,438,886	
Cuba . . . . .	441,500	
Norway . . . . .	252,657	
Sweden . . . . .	150,233	
Australia . . . . .	79,588	
Newfoundland . . . . .	45,080	
Russia . . . . .	5,100	
Canada . . . . .	5,046	
Other countries . . . . .	23,979	
Total . . . . .	2,442,069	

Recently, improved concentrating methods have made available a much larger tonnage of manganese in Cuba.

There is also a scarcity in the Lake Superior fields of extremely low-phosphorus grades, such as are held in such high esteem in England for the production of hematite iron. Only one or two mines can ship ore of less than 0·015% phosphorus content. It should be remembered, however, that the output of hematite pig in America is very small. Scarcely any acid open-hearth steel is produced except for the manufacture of steel castings. The acid open-hearth steel production in the States is about 1% of the total, as compared with almost 20% in the United Kingdom.

TABLE III.—*Typical Analyses of American Iron Ores.*

Locality and Grade, Average all 1937 Lake Superior Shipments.	Fe. %.	P. %.	Mn. %.	SiO <sub>2</sub> , %.	Al <sub>2</sub> O <sub>3</sub> , %.	CaO, %.	MgO, %.	S, %.	Ignition Loss, %.	H <sub>2</sub> O, %.	TiO <sub>2</sub> , %.	Cu, %.	Cr, %.	Ni and Co, %.
Bessemer Low-phosphoric non- Bessemer	54.66	0.038	0.36	8.14	...	...	...	...	...	9.42	...	...	...	...
Bessemer	51.44	0.075	0.71	7.42	...	...	...	...	...	12.26	...	...	...	...
High-phosphoric	51.93	0.506	0.26	7.25	...	...	...	...	...	8.01	...	...	...	...
Manganiferous	42.46	0.215	6.71	9.75	...	...	...	...	...	11.82	...	...	...	...
<i>Typical Lake Ores:</i> Mesabi, Bessemer	56.75	0.040	0.39	2.97	1.22	0.21	0.16	0.011	3.47	10.38	...	...	...	...
" " non-Bessemer	52.19	0.035	0.15	6.96	1.01	0.17	0.15	0.011	4.75	12.02	...	...	...	...
" "	52.42	0.073	0.55	4.06	2.13	0.22	0.18	0.011	5.03	12.63	...	...	...	...
" "	50.62	0.116	1.28	8.55	1.88	0.19	0.13	0.009	4.76	10.22	...	...	...	...
Cuyuna manganiferous	38.19	0.223	6.42	10.85	2.88	0.62	0.18	0.012	9.59	12.11	...	...	...	...
Menominee high-phos- phoric	51.61	0.435	0.18	4.85	2.63	0.18	0.59	0.065	8.47	7.69	...	...	...	...
<i>Southern:</i> Red ore	37.10	0.36	0.16	13.18	...	15.02	1.00	...	...	1.00	...	...	...	...
Brown ore	47.32	0.580	0.54	8.85	...	...	...	...	...	6.85	...	...	...	...
<i>Eastern magnetites.</i> Sintered concentrates:														
New York	68.50	0.003	0.065	2.76	1.06	0.54	0.40	Trace	...	...	Nil	...	...	...
Pennsylvania	58.62	0.010	0.12	8.70	2.72	2.97	3.48	0.10	...	...	...	0.18	Trace	...
New Jersey	66.50	0.04	0.03	5.60	2.32	0.24	0.12	0.010	...	...	0.35	...	...	...
<i>Eastern Texas.</i>	46.63	0.170	0.07	14.46	8.17	0.25	0.01	0.083	...	9.5	...	...	...	...
<i>New Mexico.</i>	51.10	0.065	0.50	6.00	0.50	2.40	13.40	0.40	...	...	...	0.40	...	...
<i>Colorado</i>	48.92	0.071	1.49	9.30	0.62	3.75	0.89	0.40	12.35	...	...	...	...	...
<i>Newfoundland: Wabana</i>	50.44	0.89	0.11	11.90	3.85	2.96	0.61	0.049	...	1.50	0.35	...	...	...
<i>Cuba: Mayari</i>	53.50	0.015	0.85	4.00	13.00	...	...	0.18	...	2.50	...	...	2.10	0.85
<i>Mexico: Durango.</i>	57.80	0.21	0.05	13.12	0.99	0.58	0.33	0.068	1.08	...	0.32	...	...	...
<i>Chile (used in Eastern U.S.A.)</i>	57.78	0.037	0.11	8.60	1.63	1.85	2.55	...	...	...	1.19	...	...	...

TABLE IV.—*Lake Superior Iron Ores. Typical Screen Analyses.*

Range or Grade.	Screen Size.						
	On 8 Mesh.	On 20 Mesh.	On 40 Mesh.	On 60 Mesh.	On 80 Mesh.	On 100 Mesh.	Through 100 Mesh.
Fine Mesabi, natural .	40.9	6.6	12.7	5.4	4.2	6.4	23.8
Medium fine Mesabi .	41.0	19.1	12.1	8.6	1.8	2.3	15.1
Washed Mesabi .	67.8	5.4	9.1	1.9	3.9	8.9	6.3
Marquette .	64.6	11.8	5.5	3.6	2.2	2.1	10.2
Menominee .	65.9	15.7	6.9	2.8	0.9	1.3	6.5
Gogebic .	67.9	10.9	8.3	3.9	1.0	1.5	6.5
Vermilion .	64.0	19.0	7.0	3.0	1.5	1.0	4.5
Cuyuna, natural .	75.2	10.0	5.2	2.6	1.6	1.2	4.2
Cuyuna, washed .	71.5	13.1	8.8	2.4	1.0	0.4	2.8
Sintered washed Cuyuna .	90.6	5.3	1.7	0.5	0.6	0.1	1.2

NOTE.—In most of the Lake ores as delivered to the furnaces there are so few lumps that routine screen tests are not made with screens larger than 8 mesh. From occasional tests and the opinions of those experienced in the mining and use of these materials it may be stated that the amount of lumps more than 1 in. in size varies approximately from 5% to 25%, and the average is probably from 12% to 15%.

There are, however, sources of very low-phosphorus ores, such as some of the New York State magnetites previously referred to, which could be more extensively developed if need be.

The great bulk of the Lake Superior ores is, however, eminently satisfactory for the manufacture of foundry pig iron and of pig for use in making steel by the acid Bessemer or basic open-hearth methods, which, in America, represent more than 90% of the total. The Bessemer pig iron output in 1937 was 16%, basic 66% and foundry, including malleable, 13% of the total. The remaining 7% was classified as low-phosphorus. No iron, strictly speaking, of basic Bessemer grade was made. The ores of Newfoundland and Alabama are near-basic-Bessemer quality, but pig iron made from them in America is all converted by the basic open-hearth process.

### *Iron Content.*

As to iron content, although the average is declining each year, very little ore is shipped from the Lake Superior ranges that has less than 50% of iron in the natural state except the manganiferous and so-called siliceous grades, the latter constituting only about 3.5% and 1.9% of the total. Bessemer ores were 20.2%, basic ores 70% and high-phosphorus foundry ores 4.4% of the total shipments, and the average iron contents of these were 54.66%, 51.44% and 51.93%, respectively.

*Beneficiation.*

In order to maintain this degree of richness, it has become necessary to concentrate the run-of-mine ores from an increasing number of mines. In 1937 the total tonnage of concentrates produced by various methods was :

By washing . . . . .	7,484,375 tons.
By jigging . . . . .	1,318,699 "
By magnetic roasting . . . . .	23,520 "
By sintering . . . . .	319,229 "
By drying . . . . .	408,847 "
Total concentrates . . . . .	<hr/> 9,554,670 "
Percentage of total shipments . . . . .	<hr/> 15.1%

The concentrating activities so far have been confined chiefly to the open-pit mines on the Mesabi and Cuyuna ranges in Minnesota.

The Lake Superior ores are surprisingly free from minerals obnoxious or detrimental to smelting, such as lead, zinc, titanium, arsenic, &c. Their sulphur content, for the most part, is too low to be a serious problem. The gangue-forming elements are chiefly silica and alumina, and these are generally in proportions to form a blast-furnace slag of satisfactory analysis. Very few of the ores contain much lime or magnesia, but both limestone and dolomite are to be found in or nearby all of the pig-iron-producing districts. The "natural" volume of slag resulting from the use of Lake Superior ores and Appalachian coals ranges from 800 to 1200 lb. per ton of pig iron produced, which is sufficient, in most cases, to absorb the amount of sulphur which these raw materials contain.

Washing operations have had a tendency to disturb the silica-alumina balance of the Mesabi ores, these elements being desired in the proportions of about 2.5 : 1, to form furnace slags in which the relations are as about 32 : 15. The portions being removed by washing are chiefly high in alumina, so that the effect upon slag analyses has been to reduce the alumina content, sometimes to as low as 10%, at which figure the fusion point is sometimes too low for satisfactory furnace operation. Ways and means to keep the silica-alumina relationship in the slag at the desired figure is one of the current problems of American practice.

*Reducibility.*

In addition to their richness and, generally, their all-round satisfactory chemical qualities, the Lake ores have the further advantage of being easily reducible. Mineralogically, they are practically all hematites, or mixed hematites and limonites, red, yellow, brown or blue in colour, soft and reasonably porous. Silicates of iron or other refractory minerals are not commonly found in any objectionable amounts, although these were among the con-



TABLE V.—*Lake Superior Iron Ore Shipments, 1937.*

Shipping Ports.	Amount Handled.	Ore Ranges Served.
<b>Lake Superior :</b>		
Superior . . .	22,222,000 tons	Mesabi and Cuyuna.
Duluth . . .	16,732,000 „	Mesabi.
Two Harbors . .	9,743,000 „	Mesabi and Vermilion.
Ashland . . .	5,652,000 „	Gogebic.
Marquette . . .	5,102,000 „	Marquette.
<b>Lake Michigan :</b>		
Escanaba . . .	3,148,000 „	Marquette and Menominee.
Total † . . .	62,599,000 „	
Railroad shipments	587,000 „	
Total shipments	63,186,000 „	
Receiving Ports.	Amount Handled.	Furnace Districts Served.
Sault Ste. Marie.	418,000 tons	Sault Ste. Marie, Ont.
<b>Lake Michigan :</b>		
So. Chicago . .	7,321,000 „	Chicago.
Indiana Harbor .	2,763,000 „	Indiana Harbor.
Gary . . .	5,715,000 „	Gary.
<b>Lake Erie :</b>		
Detroit . . .	1,457,000 „	Detroit.
Toledo . . .	1,924,000 „	Toledo, Hamilton (Ohio), Jackson, Portsmouth, Ashland.
Huron . . .	968,000 „	Portsmouth, Wheeling, Steubenville, Pittsburgh, and Valleys.*
Lorain . . .	3,915,000 „	Lorain, Wheeling, Pittsburgh, Valleys.*
Cleveland . . .	10,083,000 „	Cleveland, Columbus, Portsmouth, Ashland, Hamilton, Wheeling, Steubenville, Pittsburgh, Valleys,* Johnstown, &c.
Fairport . . .	1,904,000 „	Pittsburgh, Valleys.*
Ashtabula . . .	6,573,000 „	Pittsburgh, Valleys,* Wheeling, Steubenville, Johnstown and Eastern furnaces.
Conneaut . . .	9,635,000 „	Pittsburgh and Valleys.*
Erie . . .	2,745,000 „	Erie, Pittsburgh, Valleys,* Johnstown, Eastern furnaces.
Buffalo . . .	5,851,000 „	Buffalo, Eastern furnaces, Port Colborne, Ont.
<b>Lake Ontario :</b>		
Hamilton, Ont. .	698,000 „	Hamilton, Ont.
Total received †	61,970,000 „	

\* Valleys of the Shenango and Mahoning Rivers, tributaries of the Ohio.

† Ore shipped from Upper Lake ports is reported in railroad weights, whereas the receipts at the receiving ports are reported in cargo bill-of-lading weights which are arbitrarily computed at 1% less than the shipping weights, to account for moisture loss and spillage.

stituents of the original iron formations, geologically speaking, from which the present commercial ore deposits were derived, by leaching and oxidation. A few of the ores, particularly in the Marquette and Vermilion ranges, are hard and dense, apparently rendered so by the pressure and heat of igneous intrusions and by regional deformation of the iron-bearing rocks. These ores are especially well suited for use in the making of steel by the basic open-hearth process.

For the most part, however, the Lake ores are found in much the same earthy condition as they remained after the oxidation of the iron and the leaching of silica from the cherty iron formations, being compressed in slumping by little more than their own weight. Thus they occur in particle sizes that range from that of ordinary gravel to the finest powder.

### *Physical Characteristics.*

The extreme fineness of some of the Lake ores, particularly of the Mesabi, more than any other single factor, has been responsible for the development of American blast-furnace designs and operating practices in their present form, for these fine ores, while cheaply mined, easily handled and amenable to rapid reduction, could be smelted only with the greatest difficulty at the time they were introduced. Most of the changes to methods and equipment and to the furnaces themselves in the past fifty years have been inspired by an urgent need to overcome furnace troubles arising from the use of such unusually fine materials.

### *Output.*

The average amount of Lake ore shipments over the past twenty-five years has been, in round figures, about 50,000,000 tons annually, but statistical data for 1937, although based on total shipments of about 63,000,000 tons, are more satisfactory for the purpose of comparisons. There are six upper lake ports equipped for shipping and sixteen lower lake ports equipped for receiving the ore. Their importance relative to volume of ore handled is shown in Table V.

## TRANSPORTATION OF LAKE ORES.

The movement of Lake Superior iron ores is indicated diagrammatically in the map reproduced in Fig. 2. A photograph of the ore-shipping docks and coal-receiving docks at Duluth, Minnesota, is reproduced in Fig. 15.

### *Distances and Charges.*

While the longest lake haul of ore is slightly more than 1000 miles, the average is probably about 750, the average rail haul from mines to shipping port about 75, and the average rail haul from lake port to inland consuming district about 150 miles.



For these average distances the transportation charges per ton of ore from mines to furnace plant are approximately as follows :

(a) From mines to shipping port . . . . .	\$0.79
Shipping port dock charges . . . . .	0.11
Shipping port to lower lake port . . . . .	0.78
Total, alongside lakeside furnace dock . . . . .	<hr/> \$1.68
(b) From hold to rail of vessel . . . . .	\$0.14
From rail of vessel to railroad car . . . . .	0.09
Railroad freight to inland furnace, average . . . . .	1.12
Total, direct ore in cars at furnace plant . . . . .	<hr/> \$3.03
(c) From hold to rail of vessel . . . . .	\$0.14
From rail to storage on dock . . . . .	0.22
Storage charge per month, \$0.01 minimum charge . . . . .	0.01
From storage dock to cars . . . . .	0.14
Railroad freight to inland furnace, average . . . . .	1.12
Total, dock ore in cars at furnace plant . . . . .	<hr/> \$3.31

Most of the ore for inland plants goes, of course, directly to the furnace yards, thus avoiding lakeside docking and storage charges of more than 30 cents per ton.

The railway transportation charge is about one cent per mile, as compared with the lake transportation charge of approximately one-tenth of a cent per ton-mile, this notwithstanding the fact that railway cars of as much as 70 tons capacity are used and trains made up of as many as 100 cars. These figures represent commercial rates which in normal times are undoubtedly much higher than actual costs, so that companies owning their own transportation facilities can reduce transportation expenses substantially. The United States Steel Corporation, which brings down about 40% of all the Lake Superior ores, can transport Mesabi ore the entire distance to Pittsburgh over its own railways and in its own vessels.

#### *Storage Facilities.*

The lakeside plants are generally designed so that lake-going vessels can be brought alongside and unloaded rapidly and directly into the blast-furnace raw-materials storage yards. It will be kept in mind that navigation on the Great Lakes is closed by ice approximately from December 1st to May 1st, so that the furnaces in the Middle West must be equipped with storage facilities for at least half their annual requirements of ore. Ore transportation in winter by rail would be prohibitive in cost because of the distance, even if it were a feasible procedure ; but it is not, because of frequent and sometimes prolonged periods of heavy frost. At the plants remote from the coal fields provisions must also be made for the



storage of coal and sometimes of limestone, if the transportation of these is by water.

### *Lake Carriers.*

Transportation of raw materials for blast-furnaces on the Great Lakes is one of the most interesting features of the American industry (*see* Figs. 16 to 19). The Lake vessels employed are little more than self-propelled barges, with the pilot-house and officers' quarters forward, the boilers and engine room in the extreme after portion. The cargo hold occupies all the space between these, a compartment several hundred feet long, which is clear of intervening structure or equipment except bulkheads that extend from the bottom to the hatch deck at about 100-ft. intervals. After loading there is frequently less than 10 ft. of freeboard amidships, and there is no superstructure over the hatches, which are spaced only 12 ft. apart. During heavy seas, the entire length of the deck, between the pilot house and engine room, is sometimes awash, and passageway from one end to the other is cut off except by breeches-buoy.

Seaworthiness in the Lake carriers has thus been traded to a considerable extent for advantages in other respects. They are never more than a few hundred miles from sheltered harbours, and in these days shore telephones and directional radio beams greatly enhance the safety of their movements by keeping them constantly informed of impending weather changes and providing means for the accurate determination of their position under any conditions. In former years, however, storms sometimes brought disaster to the Lake fleet, as in November, 1913, when 19 vessels and 254 lives were lost in one sudden, terrific blow. Insurance on the vessels is steeply raised in the late fall and early spring.

However, the first consideration in the design of the Lake carriers has been the economical transportation and handling of ore and coal, and loading and unloading of the vessels can be accomplished with rather amazing rapidity. The steamer *D. G. Kerr* was loaded with 12,500 tons of ore in  $16\frac{1}{2}$  min. at the port of Two Harbors, Minnesota, and 12,000 tons were unloaded from the *Henry H. Rodgers* at Conneaut, Ohio, in 2 hr. 25 min. Loading is a comparatively simple operation, the ore flowing into the hold by gravity from enormous elevated bins, alongside which the vessels can be moved in such a way that there is a loading spout for every hatch. For rapid unloading, however, are required the so-called fast rigs of the Hulett type, in which the operator rides the grab bucket in and out of the hold, bringing with him a 15-ton load of ore at each trip.

The most recently built and largest carriers are about 600 ft. long, draw 22 ft. of water and will carry over 15,000 gross tons. These vessels are powered by turbines, although most of the carriers are steam-engine-driven. Speed is generally at an optimum rate

for economical operation—about 12 miles per hr. The draft of the vessels is limited by the water levels in Sault Ste. Marie Canal and certain rivers through which they must also pass. There are at present 308 vessels in the fleet of 8600 tons average capacity, and they can make from twenty to thirty return trips per season, depending upon whether or not coal is carried upon the return voyage. In 1937 over 63,000,000 tons of ore were carried.

#### APPALACHIAN COKING COALS AND COKE.

In Fig. 3 is given a map showing the distribution of coking coals in the United States; some coal and coke statistics are recorded in Table VI.

#### *River Transportation.*

While speaking of transportation, mention should be made of the movement of coal in connection with plants that are located in the Ohio River Valley, a traffic which still retains some of the picturesqueness so vividly described in the books of Mark Twain (*see* Figs. 20 and 21).

TABLE VI.—*Coal and Coke Statistics, U.S.A.*

	Net Tons.
Total production of bituminous coal, 1937 . . . . .	442,455,000
Total production of beehive coke . . . . .	3,156,300
Total production of by-product coke . . . . .	49,205,798
Total production of coke . . . . .	52,362,098

<i>Production of Coke by States, 1937.*</i>	
(Compiled by the Bureau of Mines, Department of the Interior.)	
States.	Net Tons.
Pennsylvania, Ohio, West Virginia . . . . .	28,585,601 †
Indiana, Illinois, Michigan . . . . .	10,997,816 ‡
Massachusetts, New York, New Jersey . . . . .	6,135,241 §
Alabama . . . . .	4,612,124
Colorado, Utah, Other States . . . . .	2,031,316
Total . . . . .	52,362,098

\* Preliminary.

† Includes Buffalo, N.Y.; Sparrows Point, Md.; and Ashland, Ky.

‡ Includes Missouri.

§ Does not include Buffalo, N.Y.

|| Includes Virginia and Tennessee.

Steam-driven stern-wheel towboats of very shallow draft are the motive power and the barges, each about 40 ft. wide by 200 ft. long, are lashed together in a fleet so that one trip of the propelling vessel will move about 15,000 tons of coal. The operation is called "towing," but actually the barges are always pushed rather than pulled.

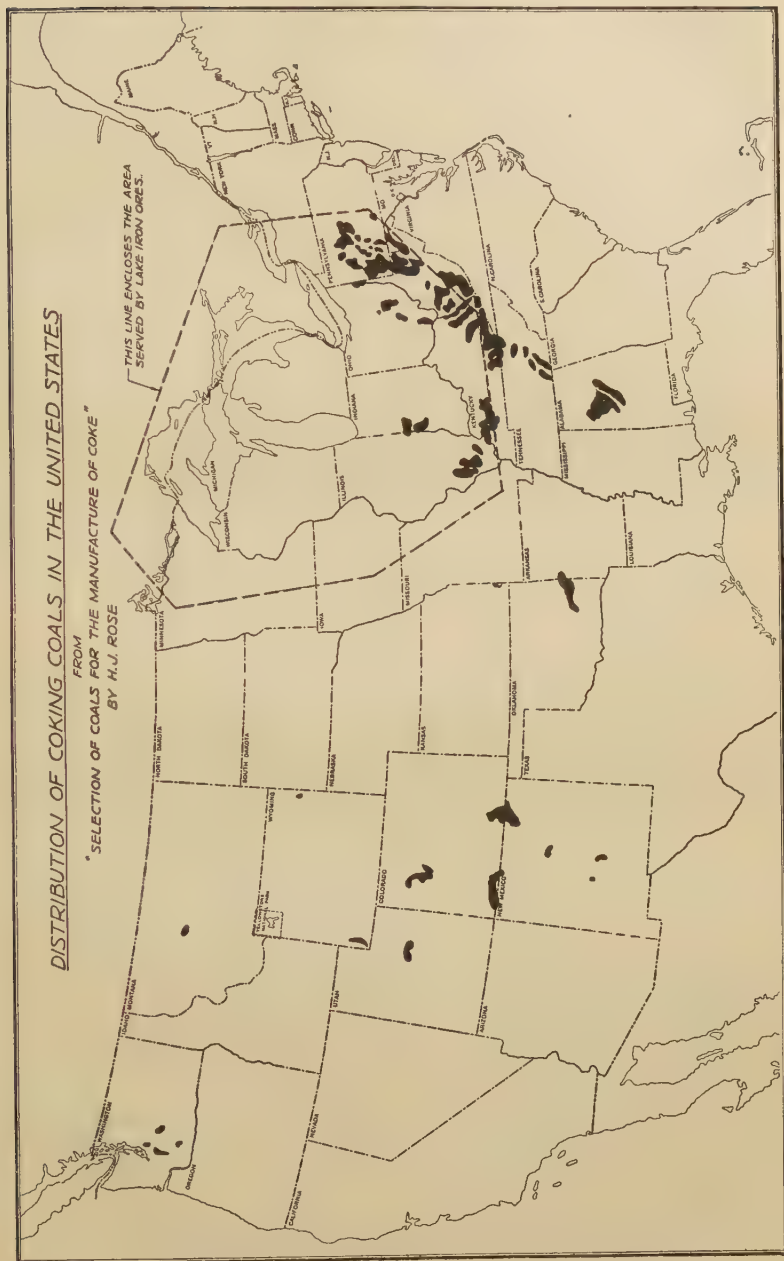


FIG. 3.—Distribution of Coking Coals in the United States. (Courtesy of the American Institute of Mining and

There is a comparatively small river traffic, about 800,000 tons annually, of coke, mostly between plants of the same or associated companies, but long-distance transportation of coke for blast-furnace use by any means, which at one time was enormous, has almost completely disappeared. With by-product ovens it has been found more economical in almost every case to locate the coke plants in close proximity to the blast-furnaces or steelworks.

Occasionally, as at Clairton, the coke plant is located centrally with respect to a number of steelworks, the coke-oven gas being distributed amongst the latter by long pipe lines. Week-end surpluses of gas at the Clairton plant are saved by the novel means of storing in an adjacent field of exhausted natural-gas wells, and when reclaimed are found to have been considerably enriched by residual natural gases which they absorb.

Coal for the Clairton plant, which is located on the Monongahela River about 20 miles above its junction with the Allegheny at Pittsburgh, is transported in barges from the upper reaches of the river, which penetrate deeply into the bituminous coal fields of south-western Pennsylvania and of West Virginia. Some of the mine entries are in the river valleys, and in many cases coal can be delivered directly into the barges after a few miles haul of the mine cars on a narrow-gauge railway. In a recent installation, coal is loaded in the mines on a belt conveyor and is thus carried directly to the river, a distance of several miles.

### *Transportation Costs.*

The plants in the river valleys at Pittsburgh, Wheeling, Ashland and Portsmouth receive practically all their coal by river at very low transportation costs. Plants along the Lakes at Buffalo,

TABLE VII.—*Cost of Carrying Coal from Mines to Blast-Furnaces.*

Location of Coal Mines.	Method of Transportation.	Cost of Transportation (Dollars) per ton of Coal from Coal Mines to Blast-Furnaces located at—						
		Pitts-burgh.	Wheel-ing.	Buf-falo.	Youngs-town.	Cleve-land.	Chi-cago.	Du-luth.
Connellsville, Pa.	All rail	1.33	1.33	2.49	1.52	2.00	3.19	...
Somerset County, Pa. Monongahela and Allegheny River Tipples	Rail and Lake	...	...	1.93	...	...	...	...
	All rail	1.49	1.86	...	1.74	...	...	...
	River	0.20	0.30	...	...	...	...	...
Pocahontas District, West Virginia	River and rail	...	...	...	1.205	1.855	...	...
	All rail	2.97	2.74	3.58	2.74	2.74	3.39	...
	Rail and Lake	...	...	2.40	...	...	2.65	2.60
West Virginia and Eastern Kentucky	All rail	2.87	2.49	3.38	2.49	2.49	3.19	...
	Rail and Lake	...	...	...	...	...	2.50	2.45
	All rail	...	1.68	2.49	1.68	2.09	3.19	...
Fairmount, W. Va.	Rail and Lake	...	...	...	...	...	2.35	2.30
	All rail	...	...	2.19	1.89	1.79	3.04	...
Butler County, Pa.	Rail and Lake	...	...	1.70	...	...	2.00	1.95
	Rail and Lake	...	...	...	...	...	2.15	2.10
Pittsburgh and West Virginia, No. 8								
Southern Illinois	All rail	...	...	...	...	...	1.75	...



Detroit and Chicago receive coal by a combination of rail and lake shipment at a considerably lower rate generally than a shipment made all the way by rail. The comparative charges for the transportation of coal to some of the principal pig-iron-producing districts are shown in Table VII.

### *Mining Methods.*

The bituminous coal fields which provide the fuel for the mid-western blast-furnaces lie along the western slope of the Appalachian Mountains, chiefly in the States of Pennsylvania, West Virginia and Kentucky. Although the coal seams are of moderate thickness, ordinarily from 4 to 10 ft., conditions generally are favourable for economic mining, the measures being comparatively flat, free from faults and near the surface. Where shafts are required they are seldom more than a few hundred feet in depth. In the less hilly portions of the field north of the Ohio River the cover is so light that some 30,000,000 tons annually are mined by stripping the overburden. About 80,000,000 tons, one-fifth of all the coal mined, are mechanically loaded, and the average output per man-day of all mines in the Pennsylvania, West Virginia, Kentucky district is almost 4.5 net tons.

### *Quality of Coal.*

The quality of the coal covers a wide range of analyses, with coal of coking quality distributed over practically the entire area. The Pennsylvania coals are, with few exceptions, however, so high in volatile content that they should be mixed with from 10 to 20% of low-volatile coals if blast-furnace coke of good grade, physically, is desired. This makes little or no difference in the cost of coke to furnace plants located on the Great Lakes, which must pay about the same freight charge on either high- or low-volatile materials, but in the Pittsburgh and Valley districts the heavier carriage charges on low-volatile coal has the effect of increasing the cost of coke from 1 to 2½ cents per ton for each 1% of low-volatile coal used. Many operators believe that this additional cost is more than regained by improved blast-furnace practice, but, nevertheless, because of the direct cost advantage of using straight high-volatile coals the furnaces in the Pittsburgh and surrounding districts have frequently had to manage with an inferior grade of coke as compared with those of the lower Ohio Valley and of the Lake district west of Cleveland. This fact has had an influence upon the trend of designs and practices in both coke-making and iron-making.

Pittsburgh district furnaces have usually had to contend also with coke that contains considerably more ash and sulphur than the western furnaces, which derive their coals chiefly from West Virginia and Kentucky. Coal washing is changing this situation slowly, but more than 85% of the American bituminous output is

still used without benefit of mechanical cleaning. The coke-ovens use mostly slack coal, the rubble and lump grades going for steam- or gas-generating purposes or for domestic use.

### *Coke-Ovens and the Blast-Furnace Plant.*

No merchant blast-furnace plant in the mid-west district making ordinary grades of pig iron has been able to survive without adjacent by-product coke-ovens, which, when located in or near large centres of population, generally derive a substantial revenue from the sale of coke-oven gas and of "domestic" coke. The numerous isolated stacks in the beehive-coke-producing area have completely disappeared, and even the few remaining merchant plants with integrated coke- and gas-making facilities in urban locations are fighting what appears to be a losing battle for their existence with steel companies that have surplus pig-iron capacity and with purveyors of natural gas. Pipe lines from the South-West fields, Kansas and Oklahoma, now deliver natural gas as far east as Toledo and Detroit, a distance of about 1500 miles, at prices which make the sale of by-product coke-oven gas difficult and of little profit. For the most part, however, iron- and steel-producing companies which have their own by-product coke works of balanced capacity are about able to offset coal conversion expenses with credits from by-products and thus limit the cost of their blast-furnace fuel to that of the coal itself.

### *Coke Quality.*

All American furnace plants have benefited immeasurably by the development of satisfactory methods for testing the physical fitness of coke and of methods and equipment for maintaining a high and uniform standard of quality in this respect. In blending, pulverising, heating of coal and in handling the coke, there have been notable advancements. Means for thoroughly cleaning the coke and grading it accurately in specified sizes are also now standard auxiliary equipment. Delivery to the furnace plants from the ovens is in many instances by belt conveyors.

## BLAST-FURNACE PLANT AND EQUIPMENT.

The location of blast-furnaces in the United States is shown in the map, Fig. 4, while Fig. 5 is a graph of the average yearly pig iron production in the States.

Fig. 6 is an elevation of a typical blast-furnace plant situated on a water-front, Fig. 7 shows the lines of modern American blast-furnaces, while Fig. 10 gives a diagrammatic cross-section through a 1000-ton blast-furnace.

Fig. 22 is a photograph of a plant with four blast-furnaces in the Cleveland, Ohio, district. It shows the facilities for unloading from Lake carriers and for transferring raw materials from the

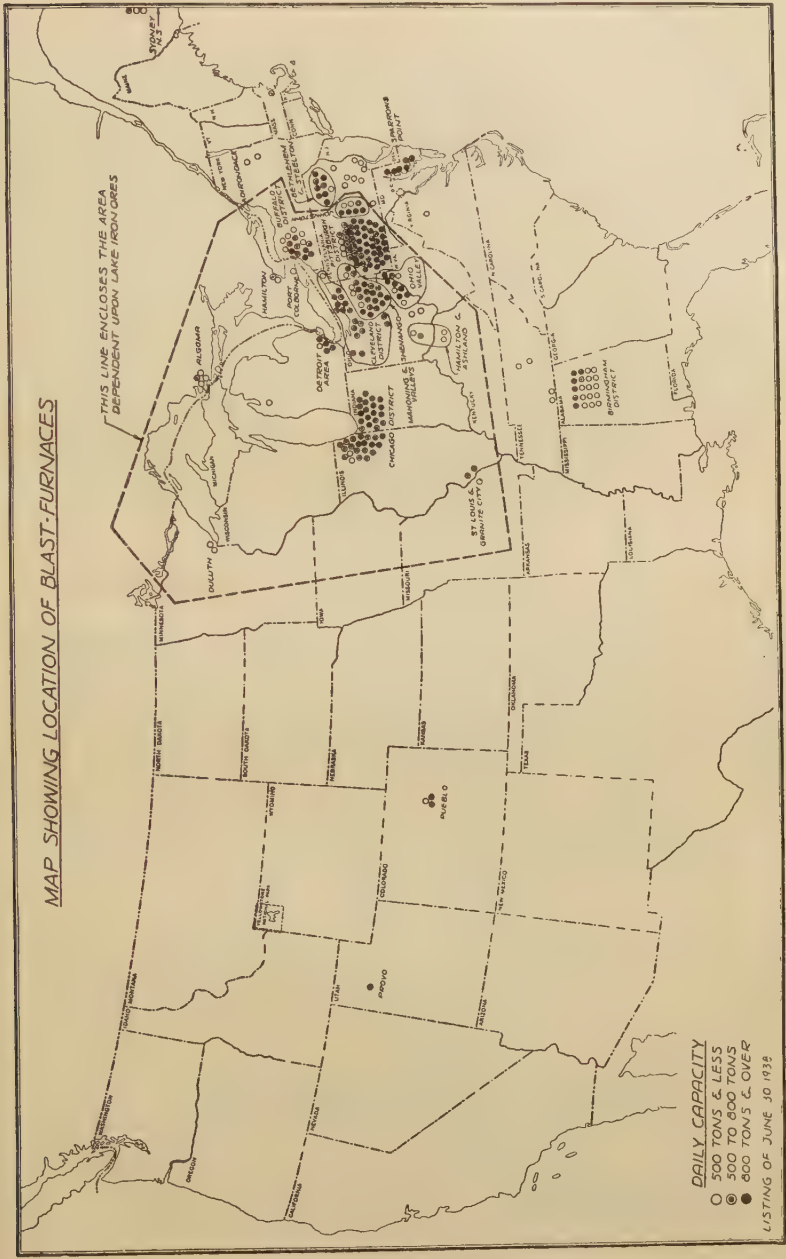


Fig. 4.—The Location of Blast-Furnaces in the United States.

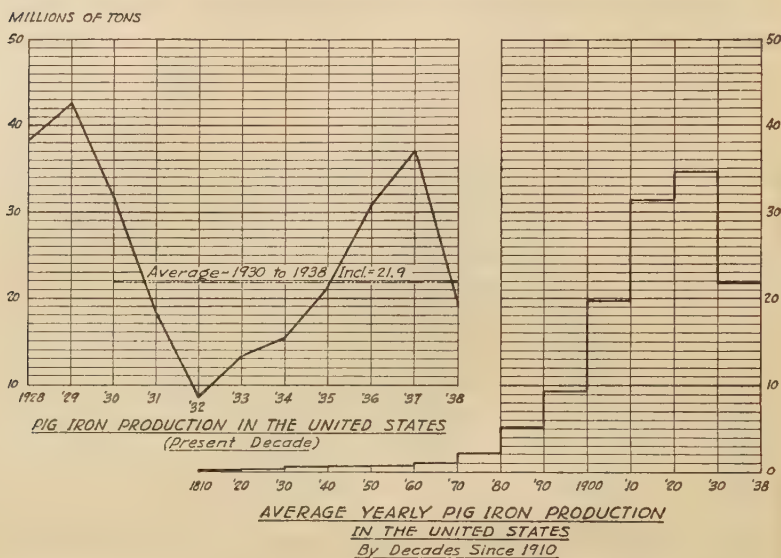


FIG. 5.—Average Yearly Pig Iron Production in the United States.

stock piles to the blast-furnace stock trestle; in the foreground are the flue-dust-recovery and sintering plants. Fig. 23 illustrates a plant with three furnaces; the modern 1000-ton furnace may be compared with the older one of about 500 tons capacity. Figs. 24 and 25 show a modern 1000-ton furnace from the cast house side and the hot-blast stove side, respectively.

TABLE VIII.—*Relative Cost (in Dollars) of Transporting Raw Materials for the Production of One Ton of Basic Pig Iron in Various Districts, 1939.*

Material.	Cleveland.	Bufalo.	De-troit.	Pitts-burgh.	Youngs-town.	Wheel-ing.	Ash-land.	Chi-cago.	Birming-ham.
Iron ore . . .	3-512	3-512	3-512	6-150	5-452	6-150	6-344	3-415	1-375
Coking coal . .	3-130	2-975	3-434	0-734	2-021	0-887	1-340	3-485	1-760
Limestone . . .	0-270	0-270	0-225	0-374	0-207	0-414	0-414	0-270	None
Total . . .	6-912	6-757	7-171	7-258	7-680	7-451	8-098	7-170	3-135

Assumptions :

(a) 1.94 gross tons (2240 lb.) of ore per gross ton of pig iron, except for Birmingham, for which a ratio of 2.50 gross tons of ore per gross ton of pig iron was used.

(b) 1.54 net tons (2000 lb.) of coal, 65% yield of furnace coke from coal, per gross ton of pig iron, except for Birmingham, for which a ratio of 2.07 net tons of coal per gross ton of pig iron was used.

(c) 0.45 gross tons of limestone per gross ton of pig iron, except for Birmingham, for which no limestone ratio was used (Birmingham ores are generally self fluxing).

(d) The computations are based on 100% ore burden of 50.0% iron content and on rail, rail-water and water transportation according to routes over which materials are usually transported to the several districts.

(e) No scrap used in burden except that produced at furnaces.



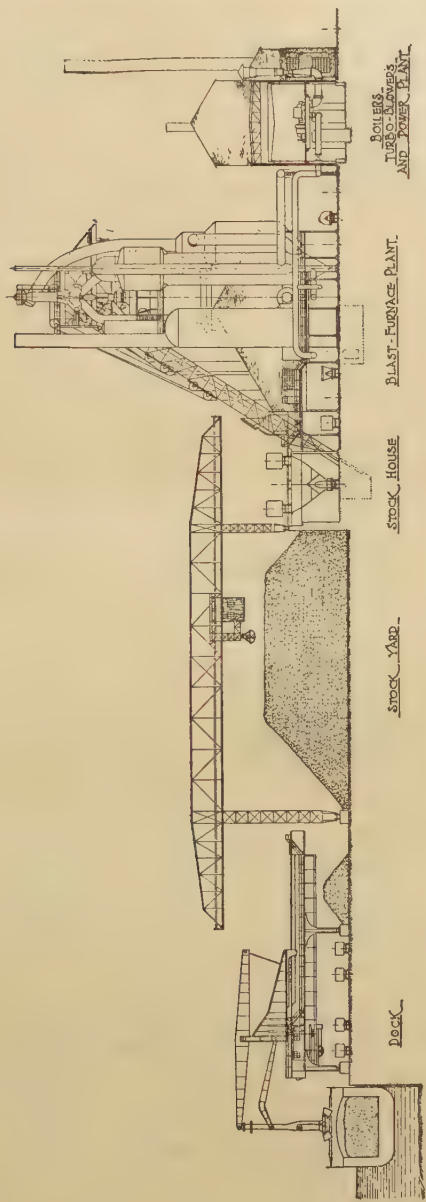
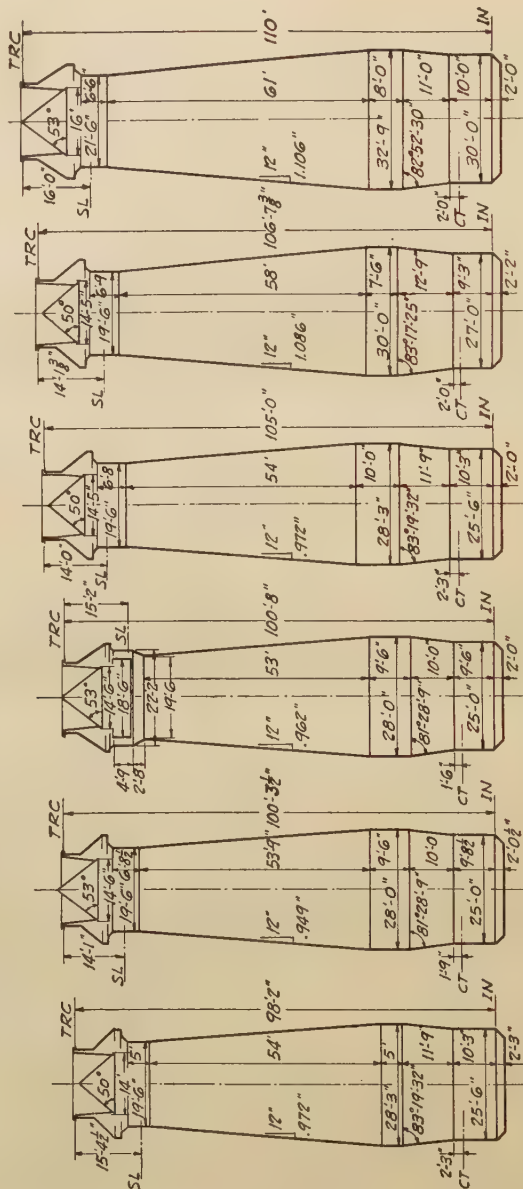


FIG. 6.---Elevation of a Typical Blast-Furnace Plant Located on a Water-Front.

# NOTATIONS

*V* - Working Volume - from centre-line of tuyeres (*CT*) to stockline (*SL*).  
*T* - Number of tuyeres.  
*C* - Number of columns.  
*SC* - Number of rows and height of stack coolers above mantle.  
*TRC* - Top of top ring casting. *IN* - Centreline of iron notch.

	36200 CU. FT.	38390 CU. FT.	37115 CU. FT.	40195 CU. FT.	44490 CU. FT.	53900 CU. FT.
<i>T</i>	16	14	16	16	16	18
<i>C</i>	8	7	8	8	8	9
<i>SC</i>	10 ROWS = 28'-0"	NONE	8 ROWS = 23'-6"	8 ROWS = 19'-0"	8 ROWS = 25'-0"	15 ROWS = 45'-6"



SUGGESTED  
 LINES

REPUBLIC  
 WARREN  
 1939

REPUBLIC  
 YOUNGSTOWN NO. 3  
 1938

GREAT LAKES  
 "C" FURNACE  
 1937

INLAND  
 NO. 5  
 1935

REPUBLIC  
 CORRIGAN-MCKINNEY NO. 4  
 1936

Fig. 7.—Lines of Modern American Blast-Furnaces.

Estimated costs of the assembly of the raw materials at various producing centres for the production of one ton of basic pig iron are given in Table VIII., while the pig iron production capacities by furnaces and by districts in the United States are listed in Table IX.

TABLE IX.—*Pig Iron Production Capacities by Furnaces and Districts in the U.S.A.*

State or District.	From Lake Ores.		From Other Ores.		From All Ores.	
	Number of Furnaces.	Annual Capacity. Gross Tons.	Number of Furnaces.	Annual Capacity. Gross Tons.	Number of Furnaces.	Annual Capacity. Gross Tons.
Pittsburgh District . . .	50	11,791,500	...	...	50	11,791,500
Chicago District . . .	40	10,635,800	...	...	40	10,635,800
Mahoning and Shenango Valleys . . .	23	5,486,000	...	...	23	5,486,000
Cleveland District . . .	18	4,198,000	...	...	18	4,198,000
Southern District . . .	...	...	22	3,259,350	22	3,259,350
Buffalo District . . .	14	3,125,700	...	...	14	3,125,700
Eastern Pennsylvania . . .	...	...	15	2,686,080	15	2,686,080
Ohio Valley, East . . .	12	2,577,700	...	...	12	2,577,700
Maryland . . .	...	...	6	1,884,000	6	1,884,000
Central Pennsylvania . . .	8	1,440,000	...	...	8	1,440,000
Detroit Area . . .	5	1,225,000	...	...	5	1,225,000
Cincinnati Area . . .	4	684,000	...	...	4	684,000
Pueblo, Colorado . . .	...	...	3	563,000	3	563,000
St. Louis District . . .	3	508,000	...	...	3	508,000
Upper Great Lakes . . .	2	277,150	...	...	2	277,150
Eastern New York . . .	...	...	3	430,000	3	430,000
Provo, Utah . . .	...	...	1	172,000	1	172,000
Massachusetts . . .	...	...	1	165,000	1	165,000
Michigan, Charcoal . . .	3	77,000	...	...	3	77,000
Virginia . . .	...	...	1	36,000	1	36,000
Total . . .	182	42,025,950	52	9,195,430	234	51,221,380

### *Raw-Material Unloading Facilities.*

Because of the importance of transporting raw materials by water and also on account of the vital need for an abundant supply of water for blast-furnace operations the larger mid-western plants are to be found in the river valleys or on the Great Lakes. Plants on the lakes are distinguished from those in the valleys chiefly by their having facilities for handling iron ore and other materials directly from vessels to storage piles, and oftentimes thence into the charging-bin system, by the same ore bridge or gantry. Such plants are generally laid out parallel to the harbour line or unloading slip. The principal plants of the Chicago, Detroit, Cleveland and Buffalo districts are of this arrangement.

The works of the Ohio River valley require facilities for unloading only coal and coke from river barges, and the coke-ovens and blast-furnaces are frequently placed at some distance from the river bank in order to obtain soil conditions more favourable for foundations. At these inland plants, iron ore and limestone being

delivered in railway cars, mechanical car dumpers are generally part of their equipment. Because of the large capacity of the railway cars, up to 70 tons, the dumpers are rather ponderous affairs, but otherwise are much the same in principle as those used in England. They are built in several types, elevating, non-elevating, stationary and travelling. The travelling dumpers move along tracks parallel to the ore storage yard wall, elevate the cars and dump the materials directly into the yard; stationary dumpers must be supplemented with ore transfer cars for the distribution of the materials into the storage yards or bins (*see* Fig. 29).

### *Raw-Materials Storage.*

Much of the ore received either in vessels or in cars during summer months goes directly into the charging bins to avoid rehandling. The ore storage yards, contrary to what seems to be occasionally believed, are of little value for blending materials, because, in reclaiming, the ore bridges cannot be operated in a manner to offset dependably the effects of the segregation of coarse and fine materials. As a matter of fact, because of these segregation effects, the operation of the furnaces will sometimes vary considerably during the months of the reclaiming period, from December to April. The finer materials from the top and centre of the piles predominate in the ore reclaimed during the early winter months and the coarser ones during the springtime. Freezing of the piles during severe winter weather adds further difficulties to reclaiming the materials in a uniformly proportioned manner.

Since provisions must be made for six months' furnace operations, the amount of storage required for each thousand tons daily blast-furnace capacity is about 350,000 tons. The facilities for storage are generally large rectangular yards all parts of which can be reached by travelling-bridge-type cranes. Ordinarily these yards are laid out parallel to the blast-furnace stock house, the foundations for which are oftentimes used to support one leg of the bridge. A cantilevered end of the bridge on the stock house side of the yard makes it possible to deliver ore into a transfer car which travels over the top of the charging-bin system.

### *Stock-House Bins.*

Delivery of coke to the furnace plant is preferably by belt conveyors if the ovens are not too far away. When serving only one or two furnaces, the belt system can be carried to the coke charging bins, but for a large group of furnaces distribution into charging bins by transfer cars makes for more flexible working conditions and clean-cut design on top of the bin system. Central coke bins, steep-sided and of comparatively small capacity, to avoid dust accumulations, discharging into stationary weigh-hoppers or directly into the furnace skips, are now almost always used.



The amount of storage capacity for ore in bins is influenced by the number of grades to be handled, but in modern plants the total is generally for about one and a half days' furnace consumption, say, fourteen bins at 250 tons capacity each. The arrangement may be a single row of double bins or a longer row of single bins, depending upon the shape of the stock house area and the number of tracks on the "trestle," which is the name given the top of the stock bins as well as the elevated approach to them.

It should be mentioned that the charging floor of modern American stock houses, for purposes of accessibility, ventilation, light and other desirable working conditions, are at or near yard level. The stock-house structure, therefore, must generally be designed for the purpose of supporting both bins and tracks and one end of the ore bridge, as well as to act as a retaining wall for the ore storage piles. These structures are sometimes built almost entirely of concrete, but, more often, partly of concrete and partly of steel.

Fig. 26 shows a modern blast-furnace stock house, with a scale car and bins of the Baker suspension type; Fig. 27 illustrates the coke feeder and weigh-hoppers in a stock house.

#### *Bottom Charging Equipment.*

The Lake ores, while not ordinarily excessively sticky, are often far from being free-running, and the amounts that must be handled are, of course, very large, amounting to as much as 2500 tons per day for a single furnace. Equipment for charging such tonnages of ore, along with the required coke, limestone and other raw materials, with a single man per turn, is one of the outstanding accomplishments of American blast-furnace design. The bins are made steep-sided, about  $52\frac{1}{2}^{\circ}$ , completely freed of internal stiffening diaphragms, and provided with gated openings that are continuous from end to end. The individual gates are small, making manual operation easy. Scale- or weigh-cars for the larger furnaces are generally of the double-compartment type, each hopper having a volume capacity at least equal to that of the skip cars, generally about 180-200 cu. ft., making it possible to draw a full charge of ore while the coke is being hoisted. Automatic recording devices on the cars check the accuracy of the weighing.

Coke is drawn from bins located centrally, above the skip, by motor-operated feeders, which also function as screens, into weigh-hoppers. Drawing and weighing the coke, dumping the weigh-hoppers through drop doors into the skips, and the complete charging, hoisting and top charging operations are automatically performed in prearranged sequence by motorised apparatus under the control of electrical devices, properly interlocked. After a charge or skip of ore is hoisted, the master control switch of the automatic charging system is thrown by the scale-car operator, who can then depart on a trip for another charge of ore while the skips are being hoisted and the bells being dumped by his mechanical helpers.

This system is known in the States as a "one-man stock house," although it requires intermittently the careful supervision of electrical and mechanical repair men.

### *Top Charging Equipment.*

For hoisting and top charging, so-called hand filling has practically disappeared. Of the automatic mechanical equipment, the single bucket, called the Neeland type, which is in such general use in Europe, has steadily lost ground in favour of the double skip. The advantages of the latter are believed to be simplicity of design and lower first cost, greater economy in operation and upkeep, greater dependability for continuous service and, particularly, greater filling capacity, a matter which has become of paramount importance with the increased output of the stacks. It must be admitted, however, that without a satisfactory distributing device on the furnace top to correct its inherently faulty distribution of stock, this almost universal application of skip filling would scarcely have been possible. For the problem of distribution, however, the McKee revolving top (Fig. 28) furnished a complete solution, and has been developed into a practically trouble-free piece of equipment.

For dumping the bells, electric bell hoists, since their advent, have generally had first preference, although occasionally equipment operated by steam or air cylinders is still used for economy in first cost. Some of this equipment has the objectionable characteristic of depending upon gravity for the opening of the large bell. A new device, called the Martin rig, provides positive opening for the large bell, and has also made possible certain other desirable changes, amongst them the elimination of the large bell beam, which, in its modern dimensions, has become clumsy and somewhat hazardous.

It is not feasible in this paper to discuss all the interesting features of modern American stocking and charging and top filling equipment, but a further understanding of them may be gained from the drawings and photographs of typical installations which supplement the text.

### *Furnace Stack.*

Although furnaces of similar designs are coming to be built in all countries, it seems reasonably correct to identify the type of construction used for the blast-furnace itself in the United States as American, for it embodies certain outstanding characteristics, including great size and structural strength, that were developed particularly to meet American conditions.

The departure from English and European types of furnaces seems to have started with the rapidly increasing demand for pig iron and the use of the fine, soft Mesabi ores which began about 1890. It may be said to have culminated, at least for a time, in the 1000-ton furnace about 1930. In these forty years the annual



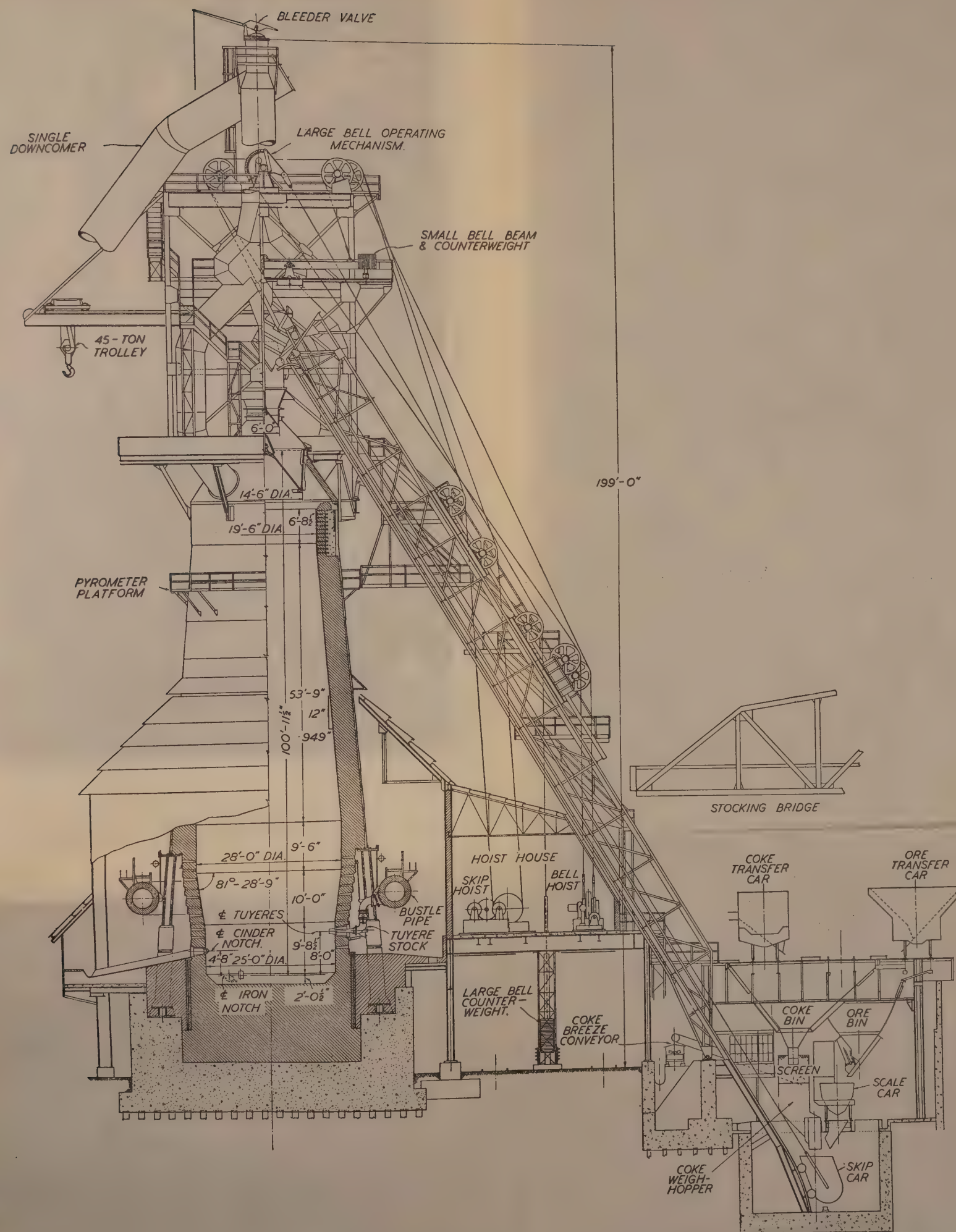


FIG. 10.—Diagrammatic Cross-Section through a 1000-Ton Blast-Furnace.

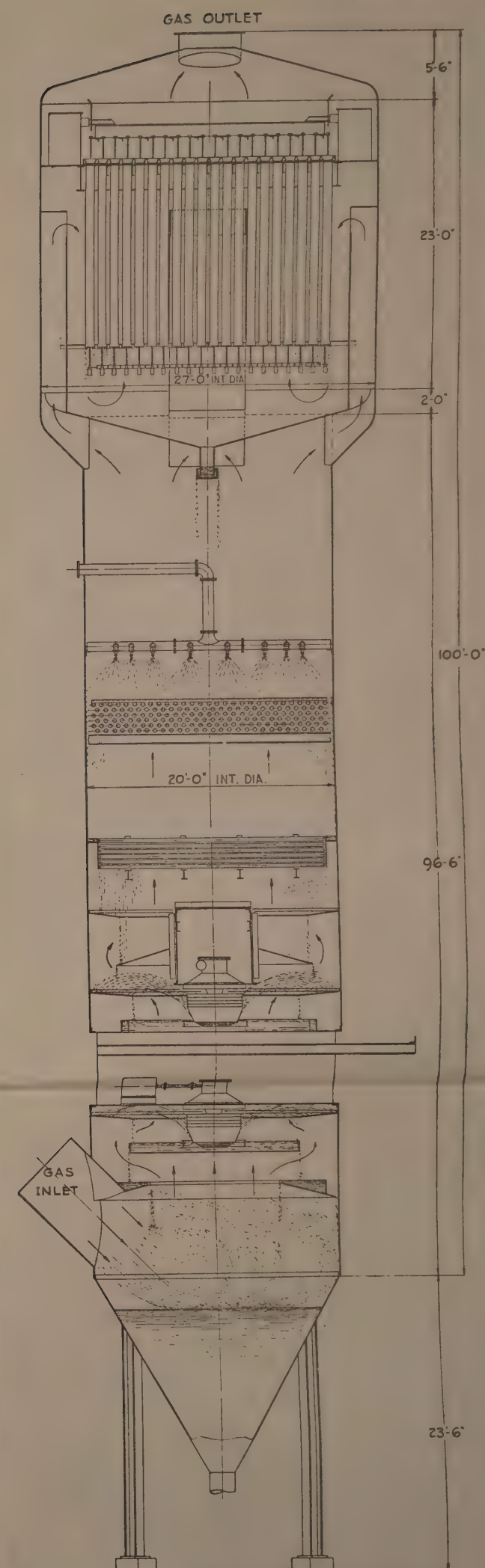


FIG. 11.—McKee Two-Stage Gas Scrubber with Research Corporation Precipitator Superimposed.

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FIG. 12.—Aerial View of Gary Works; includes the world's largest pig-iron-producing plant. Twelve modern blast-furnaces. Typical American arrangement for lake-front plant, with docks, fast unloaders, reserve stock piles for ore and limestone, striking and reclaiming bridges. (Courtesy of Carnegie-Illinois Steel Corporation.)



FIG. 13.—Portion of a Large Open-Pit Iron Ore Mine on the Mesabi Range. (Courtesy of the Lake Superior Iron Ore Association.)





FIG. 14.—Application of Transportation by Lorry to Open-Pit Mining Operation. (Courtesy of Butler Bros.)



FIG. 15.—Ore-Shipping and Coal-Receiving Docks at Duluth, Minnesota. (Courtesy of Duluth, Mesabi and Iron Range Railway Company.)



FIG. 16.—Loading of Carrier with Iron Ore at Upper Lake Port. Features of modern ore-loading dock are shown. (Courtesy of Duluth, Mesabi and Iron Range Railway Company.)



FIG. 17.—Unloading Iron Ore from Carrier at Lower Lake Port with "Fast" Rigs of the Hulett Type. (Courtesy of the Wellman Engineering Company.)

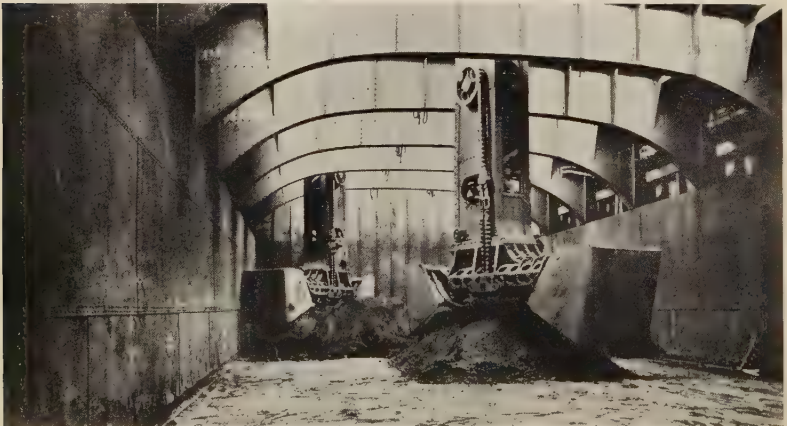


FIG. 18.—"Fast" Rigs and Operators in the Hold of a Lake Carrier. (Courtesy of the Wellman Engineering Company.)



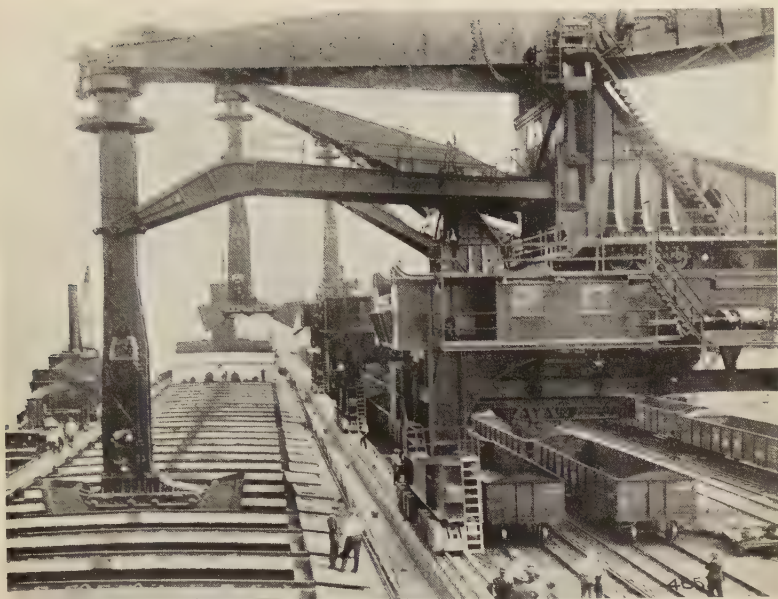


FIG. 19.—“Fast” Rigs and Lake Carrier in Position for Unloading. Arrangement of hatches and car-loading facilities are shown. (Courtesy of the Wellman Engineering Company.)



FIG. 20.—Loading Coal from Railway Cars into a Lake Carrier at a Lower Lake Port. (Courtesy of the Wellman Engineering Company.)

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FIG. 21.—“River” Coal ready for Unloading from Barges at a Coke-Oven Plant in the Pittsburgh District. (Courtesy of the Jones and Laughlin Steel Corporation.)



FIG. 22.—Plant with Four Blast-Furnaces in Cleveland, Ohio, District. Facilities for unloading from lake carriers and transferring raw materials from stock piles to the blast-furnace stock trestle are shown; in foreground flue dust recovery and sintering plants. (Courtesy of the Republic Steel Corporation.)

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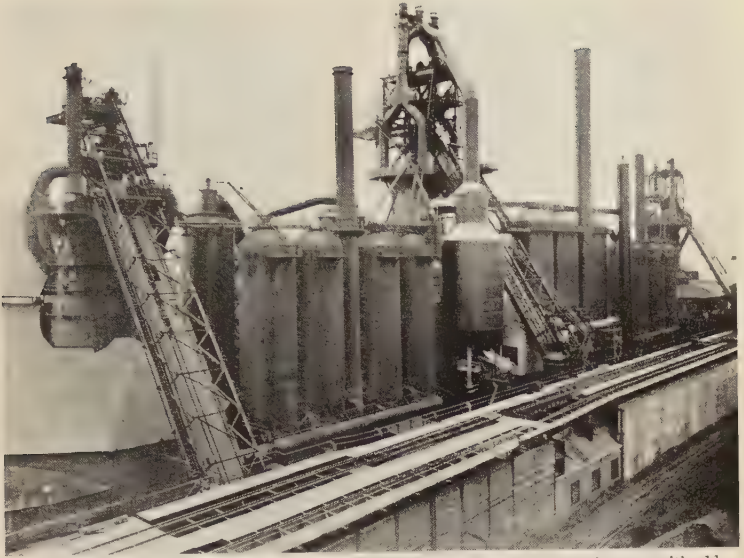


FIG. 23.—Plant of Three Blast-Furnaces. Comparison of modern 1000-ton furnace with older furnace of about 500 tons capacity. (Courtesy of the Great Lakes Steel Company.)



FIG. 24.—Modern 1000-Ton Blast-Furnace, from cast-house side. (Courtesy of the Inland Steel Company.)

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FIG. 25.—Modern 1000-Ton Blast-Furnace, from hot-blast stove side. (Courtesy of the Inland Steel Company.)

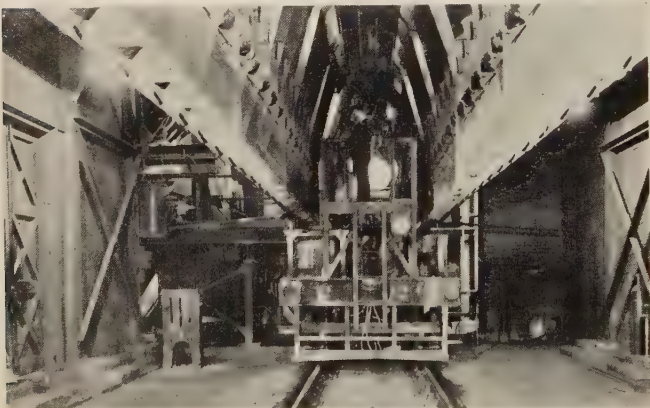


FIG. 26.—Modern Blast-Furnace Stock House, Scale Car and Bins of Baker Suspension Type. (Courtesy of the Bethlehem Steel Company.)

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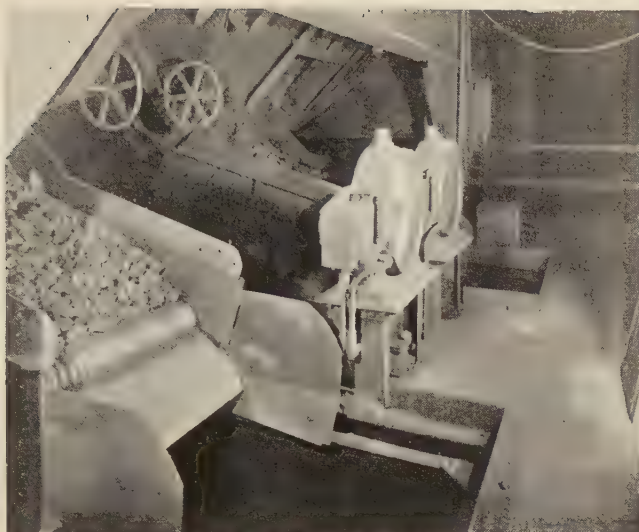


FIG. 27. Blast-Furnace Stock House, Coke Feeder and Weigh-Hoppers.  
(Courtesy of the Bethlehem Steel Company.)

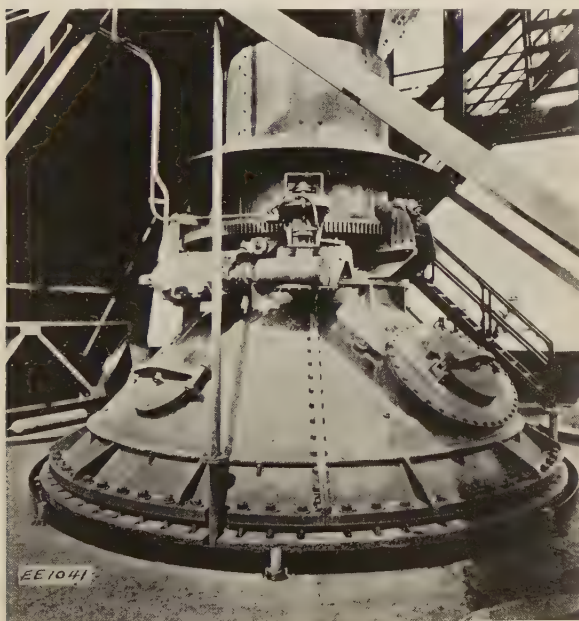


FIG. 28.—McKee Revolving Distributor for a Modern Blast-Furnace.  
(Courtesy of Arthur G. McKee & Company.)

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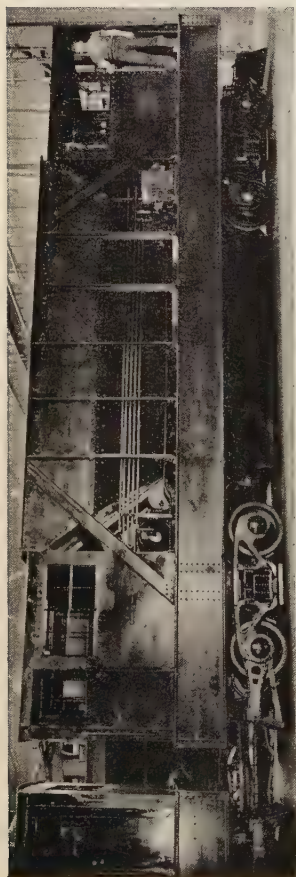


FIG. 29.—Ore Transfer Car, electrically driven, side dump, 50 tons capacity. (Courtesy of Arthur G. McKee & Company.)

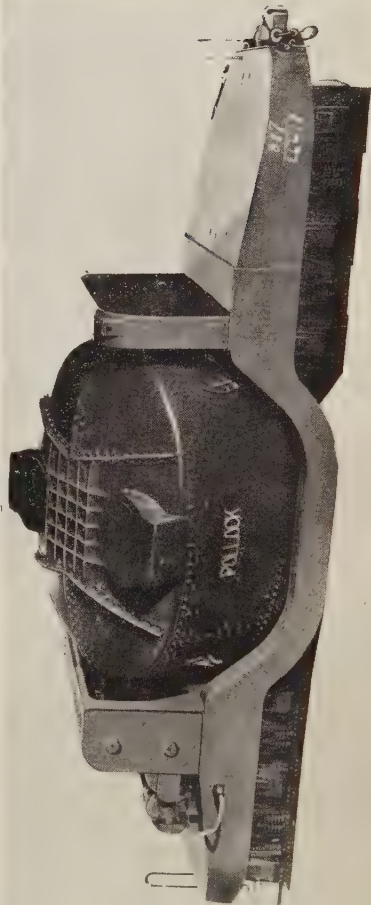


FIG. 30.—125-Ton Mixer-Type Hot-Metal Ladle. (Courtesy of the Wm. B. Pollock Company.)



FIG. 31.—Pig-Casting Machine of the Stationary Wheel Type. (Courtesy of the Steel Industries Engineering Corporation.)

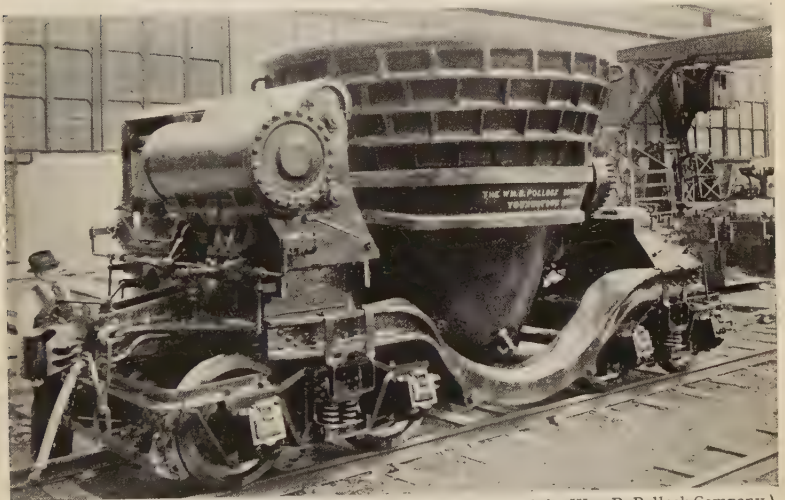


FIG. 32.—330 cu. ft. Slag Ladle, steam- or air-operated. (Courtesy of the Wm. B. Pollock Company.)





requirement for pig iron of the United States had grown from 9,000,000 to 40,000,000 tons.

Throughout this period there was good reason for increasing the output capacity per furnace and a great need for strengthening the stacks until they were strong enough to withstand the violent explosions and slips and ruptures of the hearth and bosh which frequently occurred during the early years of operations with fine ores. When the physical limits to hand-filling were reached in furnaces of about 450 tons daily output, the problem of bad distribution from the first mechanical charging devices and that of poor-quality coke from the early by-product ovens also had to be overcome.

The modern American furnace is for the most part the result of improvements that were developed to solve the operating difficulties of those years. The furnace shells were increased in thickness from  $\frac{1}{4}$  in. to  $1\frac{1}{4}$  in., the Kennedy sloping top or cone ring was invented to stiffen the top section, and for the loosely fitted combination of hopper and lip ring was substituted a single hopper tightly bolted to the cone casting, to which in turn the cone ring was riveted. The use of cast iron for hoppers and bells and other parts exposed to shock and strain was discontinued in favour of steel. American furnaces, it should be kept in mind, are designed to operate normally on from 20 in. to 40 in. water gauge of top-gas pressure.

### *Furnace Cooling.*

For the protection of the hearth and bosh, the principal development was in the method of cooling, the use of external sprays giving way entirely to that of cooling plates laid in the brickwork, thus making it possible to increase the thickness and strength of the hearth jacket or bosh bands to any desired degree, which was a long step in advance towards the safety and comfort of the workmen at the furnace front. Protection of the shell above the mantel has been achieved by similar means when deemed necessary, that is, by the circulation of water in totally-enclosed cooling plates, generally placed horizontally within the brickwork. In both the bosh and inwall these plates also serve to maintain the initially established interior dimensions of the lining much more effectively than was previously possible.

### *Furnace Lining.*

In the campaign to make the furnace lining a more lasting one, the brick manufacturing companies have played an important part in the development of refractories that are not only better suited chemically for specific purposes, but which are also remarkably accurate and uniform as to size and shape of each piece of brick. Measured by years in blast, some English furnaces have records surpassing any in the States, to our knowledge, but for tonnage

output the American stacks, with many runs of from one to two million tons and a maximum of about 2,500,000 on a single lining, are probably record holders for performances of this sort.

### *Furnace Dimensions.*

In their interior dimensions, American furnaces are characterised by large hearth and top diameters, great overall heights and low steep boshes. The dimensions of three 1000-ton furnaces, designed and built by the author's firm in 1937-38, are indicative of the comparative uniformity of ideas with regard to lines in the three rather widely separated localities of Cleveland, Detroit and Chicago. Twenty-five feet of hearth diameter and 100 ft. of height have come to be considered almost standard requirements for the output of 1000 tons per day from Lake ores, but recently there has been a tendency to still greater heights. The Republic Steel Corporation's Youngstown furnace No. 2 was rebuilt in 1938 to 25 ft. 6 in. in hearth diameter by 105 ft. high. This year a furnace 108 ft. high, having a 27 ft. hearth, will be built, and the author has recently proposed overall dimensions of 110 ft.  $\times$  30 ft. for a client who was interested in building the largest unit possible without hazardous pioneering (*see* Fig. 7).

From every point of view the big furnaces have justified themselves for American conditions. By minimising the number of stacks, operating costs, as well as charges against capital, have been greatly reduced, while, metallurgically, the results have been beneficial almost without exception.

It is also worthy of note that furnaces of generous diameter and volume have been found satisfactory and desirable in other American districts and other countries where the iron ores have differed greatly from the fine materials used in the American Middle-West—with richer and coarser ores, as in Russia and India, and with leaner and coarser ores, as in the American Southern area. One is led to the belief that the construction of furnaces of the 1000-ton or super-1000-ton class would be especially well suited for smelting the lean English ironstones at reduced costs and with improved furnace practice generally.

### *Casting Facilities.*

The facilities for casting hot metal and flushing slag from the furnaces have had to be kept in step with the increased output of the stacks. The use of sand runners and particularly the practice of skimming "by hand" would be quite inadequate for handling single casts of several hundred tons in weight. The skimming trough and iron and slag runners are now all made up in permanent heavy iron castings. The trough is generally lined with fireclay and the runners with a mixture of sand and coke breeze. The Killeen skimmer with various modifications is used at all plants.

Mud guns capable of stopping the tap-hole while the full blast pressure is on the furnace are considered essential.

For servicing iron and slag runners, the removal of scrap and expediting repair work, it is general practice to include an overhead electric travelling crane as part of the cast-house equipment, so that both miscellaneous materials and supplies can be easily, quickly and cheaply handled between the railway cars and the furnace front.

### *Metal and Slag Handling.*

The tendency towards the adoption of large units is as pronounced with respect to auxiliary equipment as in the case of the stacks themselves. Thus, in the handling of hot metal the use of mixer-type ladles of up to 125 tons capacity (Fig. 30) has proved economical by reducing the scrap losses and making it possible to deliver hotter iron to the steelworks. By this means also it has been made feasible to transport molten metal unusually long distances, as between the Hamilton furnace and the Middletown Steel Works in Ohio, which are some twenty miles apart.

As to cold pig, there is no longer any casting in sand beds in America, and the procedure of machine casting has been brought to a rather high degree of perfection (*see* Fig. 31). Not only are the pigs reduced to any desirable size, "piglets," but by improved methods the kish can be skimmed off and the pigs given a smooth, clean surface. Even the depth of chill has been reduced to satisfy certain users of foundry iron. All the big steelmaking companies now produce merchant grades of iron as a fill-in, so that for some years there has been definitely a "buyers' market" in this trade.

For slag handling, ladles of about 400 cu. ft. capacity have been the practical maximum size, warping of the pots being the limiting condition. Self-dumping ladles of the air- or steam-cylinder type (Fig. 32) are universally used. The most economical means of handling slag in the hard form, and one that isolated furnaces frequently use, is to run the material directly into twin pits, from which it is recovered by steam- or electrically-driven shovels, or by overhead cranes, and loaded into railway cars or auto trucks. Thus the cost of handling in ladles, which amounts to from 10 to 20 cents per ton of slag, is completely avoided. Having the pits alongside the furnace, however, is a nuisance from the standpoint of plant cleanliness and is hardly to be recommended for large groups of furnaces, although pits used commonly by several furnaces, located within a reasonably short distance of the plant, are probably productive of a better grade of slag for commercial uses than the high dumps so often seen in England.

### *Power Plants and Blowers.*

There are not many novelties in the features of American blast-furnace power plants, but they reflect the adoption without

unreasonable delay of improved types of steam-raising, electric-generating and air-compressing machinery.

The more recent boiler installations range from 1000 to 2000 h.p. nominal rating in size, and are generally designed for the use of thoroughly cleaned blast-furnace gas as principal fuel and pulverised coal for auxiliary firing. The pressures commonly carried are 250–400 lb., with 200–250° F. of superheat, and, depending upon the proportions of these fuels used, efficiencies of from 79 to 85% are obtained.

The generation of primary electric current is generally at 6600 V., and distribution at 220 V. A.C. and 230 V. D.C. Alternating current is now ordinarily used for all purposes except travelling cranes and skip-hoist motors. Practically all new blowing installations during the past ten years have been steam-driven turbos. It should be noted that blast pressures in the Lake ore practice normally range from 15 to 20 lb. gauge at the tuyeres with occasional periods as high as 25 lb., so that usually the blowers are designed to withstand 30 or 35 lb. Blowing is always done by volume and never from a blast line serving more than one furnace. Relief valves are generally set at from 20 to 25 lb.

### *Hot-Blast Stoves.*

Stove shells to withstand the blast pressures mentioned are now ordinarily designed of about  $\frac{5}{8}$ -in. plates, either double-riveted in both horizontal and vertical seams or welded. Only three stoves of modern design are needed even for the largest furnaces, it being possible to secure 200,000 sq. ft. of heating surface in a single 100 ft.  $\times$  24-ft. stove, and this may be considered about the maximum size for designs that are satisfactory in all respects. The theoretical heating surface requirements for a 1000-ton furnace using 1500° F. straight-line blast temperatures are only about 450,000 sq. ft. in stoves of modern construction, which are featured by thorough insulation, checker openings of about 2 in. maximum dimension and overall thermal efficiency of about 85%. The use of such small checkers makes prohibitive the use of gas that is not thoroughly cleaned, but practically all stove construction or reconstruction during the past ten years has been accompanied by the introduction of furnace-gas cleaning equipment. For gas combustion, pressure burners of either Steinbart or Freyn design are in general use.

The preferred arrangement of hot-blast stoves in America is parallel to the stock house and approximately on the centre line of the furnace and the cast house. In plants with more than one furnace the stoves for each pair of furnaces are generally grouped in a single line. For convenience in operation the stove operating platform is located as nearly as possible at the same elevation as the cast house, which in modern plants is high enough to permit hot metal and slag tracks to be kept level at the same elevation



as the general track system. Thus, cast houses and stove platforms are generally from 20 to 23 ft. above the yard level. This fact and the large increases that have been made to the height of the stacks and their superstructures has made the American smelters truly "high furnaces," as they are called by the Germans and French. The most recently built units measure more than 200 ft. from bottom to top. Elevators for carrying passengers and repair materials to various stages of the structure are now easily justified and are to be found in many of the plants.

### *Gas-Cleaning Equipment.*

The cleaning of blast-furnace gas is a phase of pig-iron manufacture in the States the development of which has probably lagged

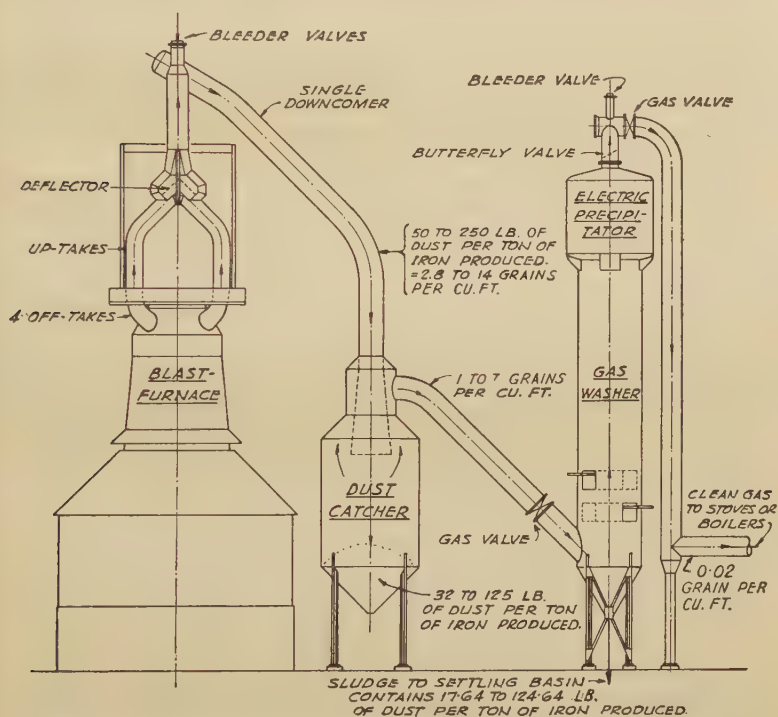


FIG. 8.—Modern American Gas-Cleaning Plant. (Diagrammatic.)

behind that of any other. Until fifteen years ago equipment for thoroughly cleansing the gas, say, to less than 0.02 grain per cu. ft., was only found in a few plants where gas blowing engines were used. These were all of the old drum Theisen type. The chief reasons for this backwardness was probably the costliness of the

gas-cleaning equipment and its operation as compared with the value of the gas when calculated from the cost of its B.Th.U. equivalent in the form of bituminous coal.

The situation began to change when the increased blast-volume requirements of the big furnaces stimulated the relining of hot-blast stoves with small checkerwork and with the utilisation of blast-furnace gas for underfiring coke-ovens and in steelworks furnaces. These measures called for thoroughly cleaned gas, and since their adoption has been rapid and widespread during the past decade, most American plants to-day have some facilities for final cleaning.

There are two methods of final cleaning in common use—Cottrell precipitators, as built by the Research Corporation, and disintegrators of the usual types; the latter are seldom installed now unless surplus gas or other sources of cheap power are available. The precipitators are somewhat higher in first cost, but generally have a wide margin in their favour in respect of power consumption and total cost per unit of gas handled. Fig. 8 is a diagrammatic representation of a modern American gas-cleaning plant.

The American development of the electric precipitator is something quite different from either the Lodge-Cottrell or the German ones, inasmuch as the method includes the thorough scrubbing and cooling of the gas prior to precipitation, the precipitators themselves operating on cold gas saturated with moisture and the dirt being precipitated and collected in the form of thin sludge. Primary washing is accomplished in towers with rain-making devices and hurdles of various types, and for the complete recovery of the dust that is removed equipment for thickening the sludge and conditioning it for the sintering plant or its return directly to the furnaces must also be included.

A substantial economy in construction costs and saving of ground space has been effected in one of the most recent gas-cleaning installations, in which the precipitator was superimposed on the primary scrubber (*see* Fig. 11). The costs of cleaning with this particular installation have seemed worth presenting, since they are about the lowest that have been obtained in American practice, so far as the author has been informed (*see* Table X.).

### *Sintering and Sintering Plants.*

The beneficiation of iron ores by concentration, crushing, sintering and grading has already been touched upon. The sintering of flue dust is not so great a problem as in past years, because the production of it has been reduced to a small fraction of former amounts by improvements to blast-furnace designs, equipment and operating methods. Sintering plants that at one time were fully occupied with the agglomeration of flue dust are now at times idle or increasingly utilised for sintering fine ore. The flue dust

that is being produced, however, is being more carefully recovered and conserved in both dry and wet forms. The finely-divided carbon which it contains is a valuable contribution to the mixture when flue dust and ore are combined for sintering purposes.

TABLE X.—*Cost of Cleaning Blast-Furnace Gas in Combination Cleaning Unit of Research Precipitator Superimposed on McKee Scrubber.*

Operating costs are taken from actual practice; construction costs are estimated for new apparatus at 1939 prices.

		Grains per Cu. Ft.
Gas entering washers : Hot and dry, dust content . . .		2.0-5.0
Gas leaving washers : Guaranteed cleanliness . . .		0.025
Performance cleanliness . . .		0.01
Rated capacity of unit : 110 thousand cu. ft. per min.		
Basis of performance data : 125 thousand cu. ft. per min.		
Operating Expenses :		
		Per 1000 cu. ft. of Gas. Quantity. Cost. Cent.
Water for primary scrubber . . . . .	25 gal.	0.0100
Water for precipitator . . . . .	2 "	0.0125
Electric power . . . . .	8.96 Wh.	0.0050
Electrical maintenance . . . . .		0.0022
Mechanical maintenance . . . . .		0.0049
Other operations—supervision . . . . .		0.0034
Total . . . . .		0.0380
Operating costs per ton of pig iron (135,000 cu. ft.) . .		5.130 cents.
Investment Expenses :		
Cost of combined units, complete . . . . .	\$137,500.00	
Interest and Depreciation per day at 13% . . . . .	\$52.00	
Cost per 1000 cu. ft. of gas . . . . .		0.029 cents.
Cost per ton of pig iron . . . . .		3.92 "
Total cost of cleaning, per thousand cu. ft. . . . .		0.067 "
Total cost of cleaning gas per ton of pig iron . . . . .		9.05 "

Sinter made from a mixture of fine ore and flue dust is generally of a better quality than that made of flue dust alone, and in sintering plants recently put down consideration has nearly always been given to the proper preparation and handling of both of these materials.

The Dwight-Lloyd and Greenawalt systems continue to be the most favoured methods of agglomeration and both types of equipment have been considerably improved in details of design and construction.

## BLAST-FURNACE PRACTICE.

American blast-furnace practice having been discussed in a previous paper before the Institute by the author as recently as

TABLE XI.—*Annual Production of Pig Iron and Ferro-Alloys (Gross Tons) in the United States.*

Year.	Anthracite Pig Iron.	Charcoal Pig Iron.	Bituminous- Coal and Coke Pig Iron.	Total Pig Iron.	Ferro-Alloys.
1810	...	...	...	54,000	...
1820	...	...	...	20,000	...
1828	...	...	...	130,000	...
1829	...	...	...	142,000	...
1830	...	...	...	165,000	...
1831	...	...	...	191,000	...
1832	...	...	...	200,000	...
1840	...	...	...	286,903	...
1842	...	...	...	215,000	...
1846	...	...	...	765,000	...
1847	...	...	...	800,000	...
1848	...	...	...	800,000	...
1849	...	...	...	650,000	...
1850	...	...	...	563,000	...
1852	...	...	...	500,000	...
1854-1858*	342,184	297,915	57,541	697,640	...
1859-1868*	540,421	241,735	174,072	956,228	...
1869-1878*	935,068	366,753	781,849	2,083,670	...
1879-1888*	1,617,606	473,187	2,573,781	4,664,574	...
1889-1898*	1,437,987	401,475	6,912,653	8,752,115	...
1899-1902*	1,526,094	360,714	13,390,594	15,277,402	...
1903-1912*	992,552	371,390	21,735,933	22,776,306	323,569
1913-1922*	181,333	296,782	30,839,349	30,791,401	526,063
1923	12,730	251,177	40,097,239	39,721,415	639,731
1924	...	212,710	31,193,080	30,874,765	531,025
1925	...	196,164	36,504,402	36,116,311	584,255
1926	...	163,880	39,208,849	38,698,417	674,312
1927	...	166,854	36,398,791	35,858,232	707,413
1928	...	142,960	38,012,754	37,401,648	754,066
1929	...	138,193	42,475,790	41,757,215	856,768
1930	...	96,580	31,655,589	31,020,907	731,262
1931	...	46,213	18,380,141	17,957,779	468,545
1932	...	15,055	8,766,398	8,549,664	231,789
1933	...	32,941	13,345,602	13,000,719	344,883
1934	...	25,834	16,138,573	15,676,889	461,684
1935	...	74,671	21,372,699	20,780,760	591,939
1936	...	77,051	31,029,187	30,216,547	812,640
1937	...	81,537	37,127,277	36,129,596	997,681

\* Average annual figures.

1933,<sup>1</sup> this subject could not be dealt with comprehensively without a considerable amount of repetition. The most important advance-

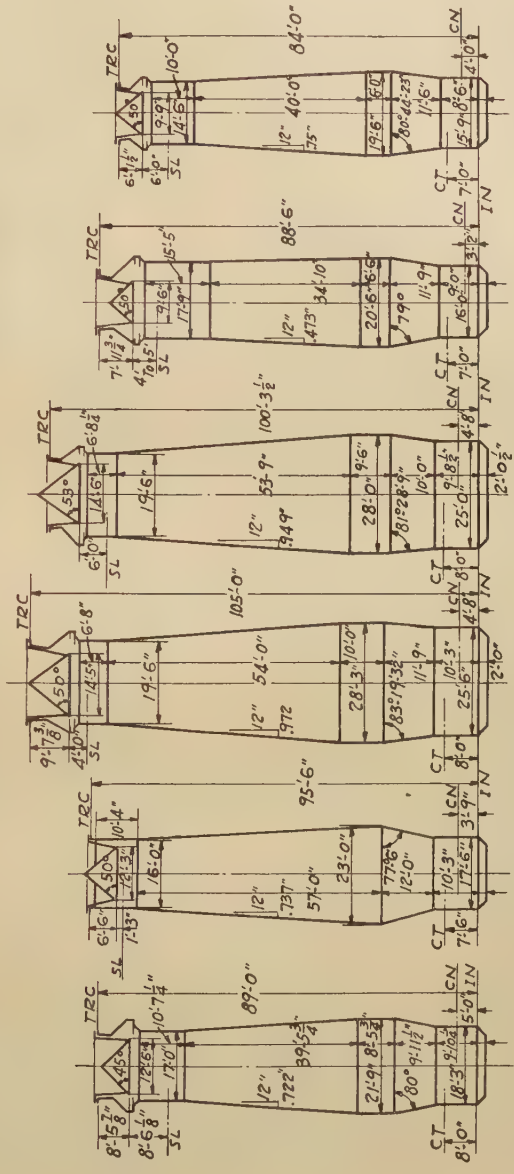
<sup>1</sup> Wm. A. Haven, *Journal of the Iron and Steel Institute*, 1933, No. I., p. 51.



V - Working Volume - From Centre-line of Tuyeres (CT) To Stockline (SL).  
I - Number of Tuyeres.  
C - Number of Columns.  
SC - Number of Rows and Height of Stack Coolers above Mantel.  
TRC - Top of Top Ring Casting. IN - Centre-line of Iron Notch. CN - Centre-line of Cinder Notch.  
LB - Cubical Capacity on Large Bell.

V	19365 CU.FT.	23000 CU.FT.	40195 CU.FT.	38390 CU.FT.	18813 CU.FT.	15059 CU.FT.
I	12	12	16	14	12	8
C	6	6	8	7	6	4
SC	10 ROWS = 26'-0"	6 ROWS = 8'-8"	6 ROWS = 16'-0"	NONE	* 10 ROWS = 35'-0"	9 ROWS = 26'-1"
LB	1000 CU.FT.	450 CU.FT.	1200 CU.FT. E.*	830 CU.FT.	830 CU.FT.	350 CU.FT.

E.\* - ESTIMATED  
\* TOP ROW NOT COMPLETE CIRCLE



BLAST FURNACE "A" NOVA SCOTIA  
BLAST FURNACE "B" EASTERN N.Y. STATE YOUNGSTOWN, OHIO  
BLAST FURNACE "C" BESSEMER PIG IRON  
BLAST FURNACE "D" CHICAGO, ILLINOIS  
BLAST FURNACE "E" BIRMINGHAM, ALA.  
BLAST FURNACE "F" UTAH  
BASIC PIG IRON  
BASIC PIG IRON  
BASIC PIG IRON  
BASIC PIG IRON  
BASIC PIG IRON  
BASIC PIG IRON

ments during the intervening period have probably been in the preparation of raw materials. Methods of blast-furnace operation have become more uniform as a result of crushing all ores to smaller sizes and the adoption in other districts of furnace lines and equipment that had been developed particularly for economical smelting of the fine Lake Superior iron ores. The tendency to larger furnaces,

TABLE XII.—*American Blast-Furnace Practice, 1939.*

Furnace.		District.		Daily average quantities	
A		Nova Scotia.		C	
B		Eastern New York State.		Youngstown, Ohio.	
				D	
				Chicago, Illinois.	
Furnace :		Grade of iron :		Basic.	
Month's production :		Month's production :		16,956 tons.	
				17,947 tons.	
<i>Materials Consumed.</i>					
(a)	Ore, sinter, scale, &c.	Lb. per ton of pig	4,103	3,293	
(b)	Coke (net).	Lb. per ton of pig	2,009	1,631	
(c)	Limestone.	Lb. per ton of pig	994	741	
(d)	O.H. slag.	Lb. per ton of pig	None	None	
(e)	Blast-furnace scrap.	Lb. per ton of pig	196	128	
(f)	Outside scrap.	Lb. per ton of pig	27	None	
(g)	Air.	Cu. ft. per ton of pig	104,200	74,000 E.	
(h)	Air.	Cu. ft. per min.	40,600	31,000 E.	
(i)	Air.	Cu. ft. per lb. of coke	51.9	45.75	
(k)	Moisture.	Grains per cu. ft. of air	4.1	N.R.	
<i>Materials Produced.</i>					
(l)	Pig iron.	Tons per day	547	598	
(m)	Slag.	Lb. per ton of pig	1,350	N.R.	
(n)	Flue dust.	Lb. per ton of pig	131	36	
(o)	Blast-furnace scrap.	Lb. per ton of pig	196	135 F.	
(p)	Blast-furnace gas.	Cu. ft. per ton of pig	143,500	N.R.	
<i>Other Practice Data.</i>					
Average blast pressure.		Lb. per sq. in.	16.6	17.5	
Average blast temperature.		° F.	1,131	1,260	
Average top gas temperature.		° F.	418	512	
Size of skip car.		Cu. ft.	110	128	
Weight of coke per skip.		Lb.	3,002	4,000	
Weight of coke per charge.		Lb.	9,900	12,000	
Weight of stone per charge.		Lb.	4,900	5,470	
Weight of ore per charge.		Lb.	19,760	24,300	
Type of top or distributor			McKee	McKee	
Sequence of filling on big bell (example : OOSCCD = ore, ore, stone, coke, coke, coke- dump big bell)			OSCCCO-D.	{ (Regular) OOO.S.D-CCC.D. (Laminated) OCOO.D-OCS.D.	
Depth of stock line from large bell, closed			8 ft. 6½ in.	10 ft. 3 in.	
Number of tuyeres			12	12	
Size of tuyeres, diameter and length			6 in. × 14 in.	6 in. × 12 in.	
Size of iron ladles.		Tons capacity	15 and 22	60	
Size of slag ladles.		Cu. ft. capacity	288	160	
Method of disposing of slag			Hot to slag dump.	Dump and expansion.	

although most rapid in the Middle-West, is to be noted in every locality.

All new furnaces built since 1933 have been of the 1000-ton class and the rebuilding of old stacks to larger sizes has continued. This procedure has been justified not only by increased output per stack and consequent reductions in the "cost above raw materials," but by markedly improved results metallurgically. Coke consumption rates have been lowered, flue dust losses have been

curtailed, and pig iron quality has been improved in analysis and uniformity. The larger furnaces have also, as is now well-known, shown a remarkable flexibility for satisfactory operation over a wide range of daily output. The annual production of pig iron and ferro-alloys is given in Table XI.

However, notwithstanding similarity of plants, equipment and

*Typical Month's Practice Data from Six Districts.*

consumed and produced.

Furnace. District.  
*E* Birmingham, Alabama.  
*F* Utah.

Notes:  
 1 ton = 2240 lb.  
 N.R. = Not reported.  
 E. = Estimated or approximate.

C. Bessemer. 30,814 tons.	D. Basic. ...	E. Basic. 15,487 tons.	F. Basic. ...
3,669	4,225	5,135	3,828
1,659	1,662	2,258	1,740
817	678	552	864
None	None	None	None
29	None	120	146
None	None	114	58
89,580	N.R.	143,250	96,800
64,000	57,833	50,000	32,026
56	50	63.4	54.8
N.R.	2.32	3.3	N.R.
994	1,000	500	473
848	900	1,800	1,553
69	32	67	50
80	132	82	46
125,000	N.R.	159,000	62,200
18.5	17.5	23	24.9
1,100	1,112	1,000	1,369
300-400	330	350	281
200	185	108	110
5,375	4,700	3,150	2,700
21,500	9,400	12,600	8,100
11,000	3,600	3,100	3,828
51,500	23,000	30,400	18,094
McKee	McKee	McKee	McKee
} (OSCCOC OSC).D.(OSCCO/OSCC).D.			
4 ft. 0 in.	7 ft. 0 in.	4 ft.-5 ft.	6 ft. 0 in.
16	14	12	8
6 in. x 15 in.	6 in. x 15 in.	6 in. x 10 in.	{ 4-6 in. x 15 in.
32	100	70	{ 4-7 in. x 12 in.
300	400	...	50
Hot to slag pits.	Hot to slag pits.	Direct to hot slag pits and also dry granulation.	330
			Hot to slag dump.

principal operating methods, the details of operation as revealed by the volume of blast, the hot-blast and top-gas temperatures, gas analysis, slag volume, analysis of slag and pig iron, rates of production and other practice data, are necessarily affected by differences in raw materials used and the geographical location of the furnaces. A thorough description of practice details in all districts would be too lengthy for inclusion in this paper, but for those who are especially interested in this phase of pig-iron manu-

TABLE XIII.—*American Blast-Furnace Practice Data,*

Furnace.	District.	Furnace.	District.
<i>A</i>	Nova Scotia.	<i>C</i>	Youngstown, Ohio.
<i>B</i>	Eastern New York State.	<i>D</i>	Chicago, Illinois.

Furnace :	A.			B.		C.				
MATERIALS CONSUMED.										
Raw Materials, Natural.	Ore No. 1.	Ore No. 2.	Roll Scale.	Sinter.	Tailings.	Ore No. 1.	Ore No. 2.	Ore No. 3.	Sinter.	Roll Scale.
Proportions used. %	96.0	4.0	...	95.8	4.2	39.7	13.6	3.5	36.5	6.7
H <sub>2</sub> O. %	2.0	2.0	...	...	...	10.05	11.70	3.00	1.0	...
SiO <sub>2</sub> . %	9.67	10.80	...	3.30	62.60	6.65	6.83	37.07	4.87	...
Al <sub>2</sub> O <sub>3</sub> . %	4.13	4.20	...	1.57	8.70	2.09	1.02	24.79	1.10	...
CaO. %	2.87	2.90	...	1.35	3.23	}	0.63	0.15	5.14	0.54
MgO. %	0.63	0.65	...	0.23	1.72		54.15	51.94	18.80	68.00
Fe. %	52.00	50.50	70.0	66.85	11.63	0.26	0.39	0.07	0.10	...
Mn. %	0.10	0.10	...	0.13	0.11	0.034	0.035	0.100	0.033	...
P. %	0.85	0.85	...	0.28	0.016	...	...	...	...	...
S. %	0.050	0.050	...	Trace	Trace	...	...	...	...	...
Ores : Hard massive hematites, crushed to 2½-in. ring.			Sinter : Magnetite concentrates sintered after fine crushing.		Ores : Mesabi and Old Range soft hematites. Sinter : Sintered magnetite concentrates.					
Fluxes.			Limestone.		Limestone.		Limestone.		Dolomite.	
Proportions used	100		100		66.6		33.4			
H <sub>2</sub> O. %	2.0		...		2.36		2.36			
SiO <sub>2</sub> . %	1.80		9.00		3.06		0.94			
Al <sub>2</sub> O <sub>3</sub> . %	1.00		3.20		0.39		0.76			
CaO. %	50.60		42.71		}	51.24	51.54		}	
MgO. %	2.00		5.03			...	...			
Fe. %	0.2		1.00		...		...			
Mn. %	...		...		...		...			
P. %	...		0.018		...		...			
S. %	...		0.29		...		...			
Fuels.			B.P. Coke.		B.P. Coke.		B.P. Coke.			
Volatile matter. %	1.64		1.1		1.5					
Ash. %	8.62		8.4		10.64					
H <sub>2</sub> O. %	...		...		2.5					
SiO <sub>2</sub> . %	...		4.30		5.20					
Al <sub>2</sub> O <sub>3</sub> . %	...		2.94		2.85					
CaO. %	...		0.20		}	0.57			}	
MgO. %	...		0.06			1.19				
Fe. %	...		0.50		89.47					
Fixed carbon. %	89.74		90.5		0.025					
P. %	N.R.		0.013		0.85-0.95					
S. %	1.89		0.64							
MATERIALS PRODUCED.										
Pig Iron.			1.07		1.22					
Si. %	1.39		0.022		0.027					
S. %	0.052		0.38		0.082					
P. %	1.43		1.75		0.30					
Mn. %	0.20		N.R.		4.30					
C. %	4.00									
Slag.			34.4		33.85					
SiO <sub>2</sub> . %	30.80		14.2		14.57					
Al <sub>2</sub> O <sub>3</sub> . %	16.22		49.2		43.91					
CaO. %	47.52		}		6.25					
MgO. %	3.31				0.33					
FeO. %	0.47		1.4		1.72					
S. %	2.62		...		...					
TiO <sub>2</sub> . %	0.39		0.8		...					
Mn. %	...									
Gas.			11.9		14.4					
CO. %	12.86		28.3		25.4					
CO. %	28.38		...		...					
CH <sub>4</sub> . %	...		2.5		2.3					
H <sub>2</sub> . %	1.34		57.3		57.9					
N <sub>2</sub> . %	57.42		99.0		89.6					
B.Th.U.	100.5		2.38		1.76					
CO/CO <sub>2</sub> ratio	2.21									



# 1939. *Analyses of Raw Materials and Products.*

Furnace. District.  
*E* Birmingham, Alabama.  
*F* Utah.

Notes :  
 N.R. = Not recorded.  
 E. = Estimated.

D.					E.			F.		
Ore No. 1.	Ore No. 2.	Ore No. 3.	Ore No. 4.	Sinter.	Ore No. 1.	Ore No. 2.	Sinter.	Ore No. 2.	Ore No. 3.	Sinter.
7.4	20.5	41.0	14.3	16.8	23.5	49.0	27.5	27.4	36.8	35.8
16.08	16.15	12.63	10.21	2.50	9.0	2.0	1.7	3.15	3.15	3.0
9.05	3.73	7.55	10.68	12.11	8.75	13.30	12.50	6.85	6.62	9.0
3.12	1.73	2.32	1.98	3.66	3.40	3.00	3.00	1.67	1.67	2.08
0.80	0.18	0.10	0.19	2.43	...	18.50	10.08	3.06	3.06	3.38
0.19	0.37	0.09	0.10	0.30	...	0.70	...	1.25	1.25	1.49
36.72	50.27	49.68	51.45	53.98	47.8	31.9	46.9	55.32	55.58	55.5
6.32	1.17	0.73	0.36	1.20	0.45	0.14	...	0.10	0.10	0.22
0.208	0.080	0.065	0.049	0.119	0.35	0.29	...	0.07	0.07	0.08
0.014	0.013	0.010	0.011	...	...	...	...	0.023	0.020	0.025
<i>Ores</i> : Mesabi and Old Range Soft hematites.					<i>Ore No. 1</i> : Lumpy brown hematites, crushed to -3 in.			<i>Ores</i> : Dense hematite containing also about 12% of magnetite. Crushed, graded and charged in 3 sizes: -2½ to +1½ in.; -1½ to +¾ in.; -¾ in.		
<i>Sinter</i> : Sintered magnetite concentrates.					<i>Ore No. 2</i> : Hard massive hematites, crushed to -1 in.			<i>Sinter</i> : Sintered fines from ore and flue dust.		
<i>Sinter</i> : Sintered flue dust and -¾ in. hard hematites.					Dolomite.			Limestone.		
Limestone (dry analysis).					100			45.0		
N.R.					N.R.			0.4		
0.63					2.71			2.4		
0.29					1.59			0.2		
53.83					29.55			52.4		
1.32					19.20			1.2		
0.10					...			0.4		
0.006					...			...		
0.003					...			...		
0.026					...			...		
B.P. Coke.					B.P. Coke.			B.P. Coke.		
0.42					1.47			...		
5.37					11.73			9.05		
5.21					...			4.5		
2.27					6.32			3.97		
1.78					3.75			2.56		
0.33					0.20			0.73		
0.31					0.35			0.07		
0.18					0.98			0.95		
94.21					85.80			90.03		
0.005					0.06			0.033		
0.57					0.74			1.05		
1.08					0.97			1.06		
0.025					0.035			0.036		
0.160 E.					0.75			0.18		
1.80 E.					0.35			0.53		
N.R.					4.05			4.02		
37.26					37.92			37.9		
14.85					13.52			11.1		
43.49					38.97			33.3		
2.00					7.06			0.60		
...					N.R.			1.03		
1.11					1.04			0.83		
...					...			...		
...					0.30			...		
14.5					11.9			16.1		
26.2					27.5			26.0		
0.02					N.R.			0.35		
2.4					N.R.			1.4		
56.7					60.6			57.1		
N.R.					100.0			90.0		
1.81					2.30			1.62		

TABLE XIV.—American Blast-Furnace Practice Data, 1939. Furnace Dimensions.

Furnace.		District.		Furnace.		District.	
A	B	C	D	E	F	G	H
Grade of pig iron :	A.	B.	C.	D.	E.	F.	G.
	Basic.	Basic.	Acid Bessemer.	Basic.	Basic.	Basic.	
A Height overall, iron notch to top of top ring casting	89 ft. 0 in.	95 ft. 6 in.	105 ft. 0 in.	100 ft. 8½ in.	88 ft. 6 in.	84 ft. 0 in.	
B Height, cinder notch above iron notch	5 ft. 0 in.	3 ft. 9 in.	4 ft. 8 in.	4 ft. 8 in.	3 ft. 2 in.	4 ft. 0 in.	
C Height, tuyeres above iron notch	8 ft. 0 in.	7 ft. 6 in.	8 ft. 0 in.	8 ft. 0 in.	7 ft. 0 in.	7 ft. 0 in.	
D Height of hearth	9 ft. 10½ in.	10 ft. 3 in.	10 ft. 3 in.	9 ft. 8½ in.	9 ft. 0 in.	8 ft. 6 in.	
E Height of bosh	9 ft. 11 in.	12 ft. 0 in.	11 ft. 9 in.	10 ft. 0 in.	11 ft. 9 in.	11 ft. 6 in.	
F Height of straight section at mantel	8 ft. 5½ in.	None	10 ft. 0 in.	9 ft. 6 in.	6 ft. 6 in.	6 ft. 0 in.	
G Height of sloping inwall	39 ft. 5½ in.	57 ft. 0 in.	54 ft. 0 in.	53 ft. 9 in.	34 ft. 10 in.	40 ft. 0 in.	
H Height of straight section at stock line	10 ft. 7½ in.	10 ft. 4 in.	6 ft. 8 in.	6 ft. 8 in.	15 ft. 5 in.	10 ft. 0 in.	
I Height, stock line to bell in closed position	8 ft. 6½ in.	1 ft. 3 in.	4 ft. 0 in.	...	4 ft. to 5 ft.	6 ft. 0 in.	
J Height, bell in closed position to top of top ring casting	8 ft. 5½ in.	6 ft. 6 in.	9 ft. 7½ in.	...	7 ft. 1½ in.	6 ft. 1½ in.	
K Diameter of hearth	18 ft. 3 in.	17 ft. 6 in.	25 ft. 6 in.	25 ft. 0 in.	16 ft. 0 in.	15 ft. 9 in.	
L Diameter of bosh	21 ft. 9 in.	23 ft. 0 in.	28 ft. 3 in.	28 ft. 0 in.	20 ft. 6 in.	19 ft. 6 in.	
M Diameter of stock line	17 ft. 0 in.	16 ft. 0 in.	19 ft. 6 in.	19 ft. 6 in.	17 ft. 9 in.	14 ft. 6 in.	
N Diameter of large bell	12 ft. 6 in.	12 ft. 3 in.	14 ft. 5 in.	14 ft. 6 in.	9 ft. 6 in.	9 ft. 9 in.	
O Diameter of small bell	5 ft. 6 in.	5 ft. 6 in.	6 ft. 0 in.	6 ft. 0 in.	4 ft. 8 in.	3 ft. 10 in.	
P Angle of bosh	80°	77° 6'	83° 19' 32"	81° 28' 9"	79°	80° 44' 23"	
Q Angle of inwall	¾ in. in 12 in.	¾ in. in 12 in.	1 in. in 12 in.	¾ in. in 12 in.	¾ in. in 12 in.	¾ in. in 12 in.	
R Angle of bell	45°	50°	53°	53°	50°	50°	
S Thickness of hearth wall	40½ in.	3 ft. 0 in.	36 in.	36 in.	36 in.	36 in.	
T Thickness of bosh wall	23 in.	average	31½ in.	31½ in.	Blocks	27 in.	
U Thickness of inwall at mantel	45 in.	4 ft. 9 in.	49½ in.	4 ft. 6 in.	26½ in. to 14 in.	45 in.	
V Thickness of inwall at stock line	45 in.	3 ft. 9 in.	42 in.	...	34½ in.	36 in.	
Number of rows of plates above mantel	10	6	6	None	10, top row not complete circle	9	
Total height of plates above mantel	26 ft. 0 in.	8 ft. 8 in.	16 ft. 0 in.	None	35 ft. 0 in.	26 ft. 1 in.	
Effective cubic capacity on large bell	1,000 cu. ft.	450 cu. ft.	1,200 cu. ft.*	830 cu. ft.	830 cu. ft.	350 cu. ft.	
Cubic capacity of furnace from centre-line of tuyeres to stock line or to 6 ft. below large bell in closed position	19,365 cu. ft.	23,000 cu. ft.	40,195 cu. ft.	38,390 cu. ft.	18,813 cu. ft.	15,059 cu. ft.	
Number of tuyeres	12	12	16	4	12	8	

\* Estimated.

facture, the data that will be found in Tables XII., XIII. and XIV. should be interesting and instructive. They provide an unusually comprehensive and complete picture in statistical form of typical blast-furnace operations in each of the more important producing areas. The lines of regional blast-furnaces for which operating data are presented are shown in Fig. 9.

The general statistics used in the paper have been drawn chiefly from United States Government publications, Bulletins of the American Iron and Steel Institute and the 1938 Year Book of the Lake Superior Iron Ore Association. To these and other sources of information the author acknowledges his indebtedness, and he also wishes to express his appreciation to many friends and associates in the industry who have contributed material for the paper and assistance in its preparation.

*DISCUSSION.*

In the absence of the AUTHOR, this paper was presented by Mr. JAMES HENDERSON (Vice-President and Hon. Treasurer).

Mr. JAMES HENDERSON (Vice-President and Hon. Treasurer, London), in presenting the paper, said that everyone would regret the absence of the author, due to the war. In May of last year he (Mr. Henderson) had attended the Annual Meeting of the American Iron and Steel Institute in New York as the envoy of the British and the guest of the American Institute, and there he had presented a paper entitled "The Manufacture, Sale and Use of Iron and Steel in Great Britain," which had a most flattering reception, and it was suggested that the British Iron and Steel Institute might invite a similar visit from a representative of the American Institute. For obvious reasons that was not practicable at the moment, but the present paper, though carrying no official status, was greatly to be welcomed.

When in America he, like so many other visitors from Great Britain, was received most hospitably, and had many more invitations to visit plants than he could possibly accept, and he was both surprised and delighted by the frankness with which technical data and information were offered to him; there was undoubtedly a very fine spirit of goodwill among the technical executives of plants, which were sometimes keenly competitive on the sales side. It was in that spirit that the present paper had been compiled and written, and data had been supplied by companies for publication in a unique manner.

As for the author's qualifications for writing the paper, it was only necessary to mention that he was a Vice-President of the firm of Arthur McKee & Co. of Cleveland, who were leading consultants in the U.S.A. and who recently undertook the design and superintended the erection of two large blast-furnaces in Britain.

Blast-furnace practice had to-day reached a very efficient standard in America, and while in Britain they could not hope to rival the scale of American operations, they could learn much from them.

Dr. T. P. COLCLOUGH (London) said that the Institute was to be congratulated on securing a paper from a man of such authority and eminence as Mr. Haven, a man with world-wide experience and with first-class contacts with the problem in almost every country in the world. The paper would be of the greatest value not only to those now engaged in the industry but also to those who would follow them. The way in which the enormous problem of handling very large tonnages in an expeditious manner had been overcome was an excellent lesson in what could be done. The author's review



of the distribution of ores and of coals was equally masterly, and he then went on to the development of the blast-furnace itself and the technique of the different sections of the plant. Such a paper was really not to be discussed in open meeting, but rather in one's own works across the drawing-office table, with plans and diagrams in front of one, so as to go into details and see where improvements could be made. He would like, however, to draw attention to three points.

The first was the question of gas cleaning. The author rightly said that in the matter of gas cleaning America had lagged a long way behind the developments in Britain and in Europe. The Americans had not the urge to make the full use of blast-furnace gas which had been felt on this side of the Atlantic, and their entry into this field had been at a somewhat late date. The American development of the electric precipitator differed from the Lodge-Cottrell and the German ones, the author said, "inasmuch as the method includes the thorough scrubbing and cooling of the gas prior to precipitation." For once, the author did not seem to have been as fair as he might have been to the developments on this side of the Atlantic. This work had been carried out not only in America but also by Lodge-Cottrell and in Germany. The first plant ever built in the world for the electric precipitation of wet cold gas was developed in Germany and was erected at Lübeck, on the shores of the Baltic. Then followed a proposal by the American branch of Lodge-Cottrell for a plant in Australia. The next development, and he believed the first complete installation, was that erected at Ebbw Vale by the Lodge-Cottrell Company. Undoubtedly the best system of cleaning blast-furnace gas was a combination of the wet-washing and the electrostatic methods. American practice was going more and more in that direction, and they were getting the results which had been attained on this side of the Atlantic.

He would draw attention to Table X., where the figures given for guaranteed cleanliness and performance cleanliness were somewhat higher than would be expected on this side of the water, where the performance obtained both in Britain and in other countries was of the order of half that dust content. A word of warning should be given with regard to the costs shown in that Table. There was nothing more misleading than a comparison of costs between one country and another unless all the facts were known. The costs given in the Table were reasonable under the conditions in which the work was done, and were exceeded in other plants by the cost of water alone. In the case referred to, all that had to be paid for the water was the cost of pumping it from a lake and allowing it to run back by gravity—the simplest possible cost one could have. The power was cheap, and if the labour cost was worked out it would be found to come out to half a man. Unfortunately, in Britain they were not allowed to use half a man on any plant. There was perhaps too high a standard on gas-cleaning plants in

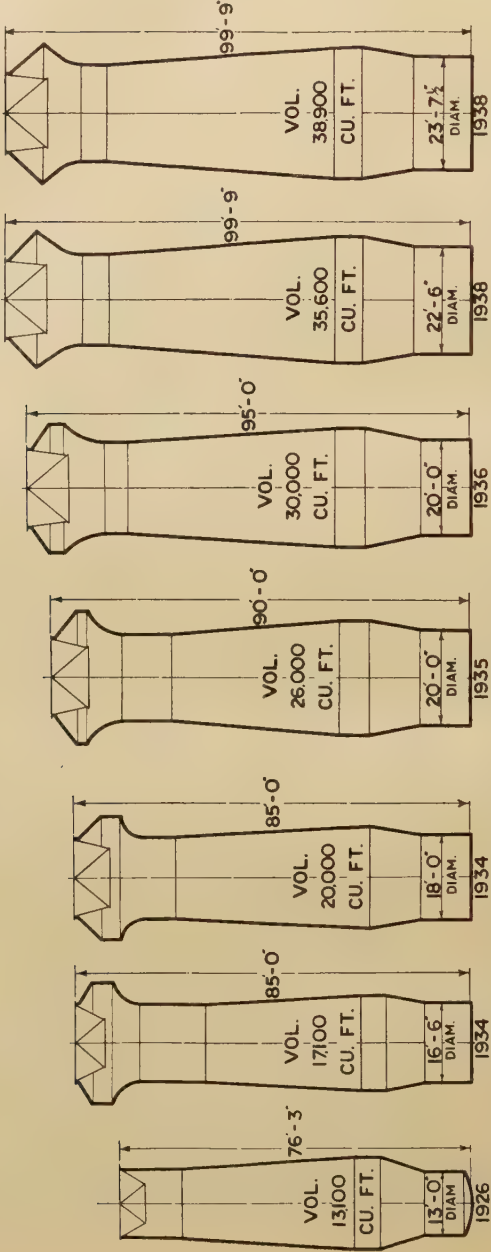


FIG. A.—Development of the Blast-Furnace in Britain and on the Continent between 1926 and 1938.

Great Britain, and one man was not permitted to be alone in the possible danger of such a plant, so that the labour costs shown must be multiplied by 4.

The next point which he wished to discuss was of interest to everyone, and was the size and capacity of the blast-furnace unit—a hardy annual, but one which was always worthy of further discussion. It would be recalled that the Blast-Furnace Practice Sub-Committee of the Iron and Steel Industrial Research Council had stated <sup>1</sup> at the Annual Meeting of the Institute in 1934 that the blast-furnaces in England had the lowest production of any furnaces in the world, that there were perhaps reasons for that, that the necessity for flexibility had limited the size of even the largest furnaces of the country and that it might be expected that that policy would be continued in the future, and that the individual furnace capacity would be increased only so far as was compatible with flexibility and low operating costs. Personally, he would suggest that no-one ever increased the size of blast-furnaces except in those conditions. The present author said: “All new furnaces built since 1933 have been of the 1000-ton class and the rebuilding of old stacks to larger sizes has continued. This procedure has been justified not only by increased output per stack and consequent reductions in the ‘cost above raw materials,’ but by markedly improved results metallurgically.” The value of such a paper as that under discussion lay in what could be learned from it for conditions on this side of the Atlantic. The author said: “One is led to the belief that the construction of furnaces of the 1000-ton or super-1000-ton class would be especially well suited for smelting the lean English ironstones at reduced costs and with improved furnace practice generally.” It might be of interest to recall what was the actual story in Britain. In 1934, at the time when the report of the Blast-Furnace Practice Sub-Committee was being presented, a new furnace had been built in this country, replacing one of the small, old-type furnaces making 150 tons a day, with a hearth diameter of 13 ft. and a volume of 13,100 cu. ft. The new furnace, to try out the new ideas, was increased to the largest capacity possible on the foundations, with a 16 ft. 6-in. hearth and a volume of 17,100 cu. ft., and it had a capacity of 350 tons a day, as compared with 150. Six months later, it was followed by another furnace with a hearth 18 ft. in dia., a volume of 22,000 cu. ft. and a working capacity of 400 tons a day. That was followed a year later by another furnace 20 ft. in dia., a volume of 26,000 cu. ft. and a daily capacity of 450 tons, working on ores containing 30% of iron, not 50%. That was followed by another, 20 ft. in dia., 95 ft. in height, with a volume of 30,000 cu. ft. and a daily capacity of 500 tons of pig iron, and later by furnaces in Europe of 22 ft. 6-in. dia. and 35,600 cu. ft. capacity, making 550 tons a day, and of

<sup>1</sup> First Report of the Blast-Furnace Practice Sub-Committee, *Iron and Steel Institute*, 1934, *Special Report No. 6*.

23 ft. 7½-in. dia. and 38,900 cu. ft. capacity, making 600 tons of pig iron a day, working on low-grade ore of 25-30% iron content. This growth was illustrated in Fig. A.

The remarkable thing was that with every step of development there was a greater and greater economy in operation. Mr. Henderson, in introducing the paper, might have supplemented his reference to the two furnaces in Britain that he mentioned. The company owning those furnaces was to be congratulated on its courage in building a 22-ft. furnace which, using the low-grade Lincolnshire ores, had a daily productive capacity of about 500 tons, with a coke consumption which five years ago would have been regarded as unbelievable. There was every reason for reversing the policy outlined five years ago and concentrating the production of pig iron in Britain, especially for steelmaking purposes, in these economic large-producing units.

Another point which was of value was how it came about that by an increase in volume from 13,000 to 39,000 cu. ft. it was possible to increase the productive capacity from 150 to 600 tons per day. The fundamental point in designing a blast-furnace was to regard it only as a furnace, working on the same principles as any heating furnace. The optimum results in a blast-furnace could be obtained only when the material in its passage down the stack was thoroughly preheated and reduced by the waste gases passing upwards. When those two things coincided and no coke was used in the hearth of the furnace for melting or heating the material, that was the ideal condition. In that connection, the fundamental problem was the preparation of the materials that were to be charged into the furnace. America had an enormous advantage there, because the ores used were all under 1 in. in size. In England they suffered from the terrible crime of charging blast-furnaces with material 2 ft. and 2 ft. 6-in. in dia. The introduction of the large digger for the mines was a godsend to the miner and a curse to the blast-furnace man. In England, so far as the charging of blast-furnaces was concerned, apart from a few modern plants, they were living in the days of barbarism. When he was in China four years ago he had the privilege of seeing some of their primitive methods of making pig iron, and he was struck by the fact that their practice, which had probably been in operation for two thousand years, was far in advance of 90% of that in England and equal to anything that he had seen in America. The Chinese operators took the ore from the mine, screened it, rejected all the lumps and worked on the fines, and then coolies were employed to smash up the lumps into small pieces. If that were done in England, where at the present time a greatly increased production of pig iron was required, it would be the quickest, most effective and most economical way of getting that increased production from existing equipment. By crushing, screening and sintering the ores the production of the furnaces could be increased by 15%.

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*CORRESPONDENCE.*

Mr. G. A. V. RUSSELL (Sheffield) wrote that he had read with interest Mr. Haven's comprehensive account of modern American blast-furnace practice and of the raw-materials basis of the blast-furnace industry in that country. Perhaps the most striking characteristics of American practice to a European observer were the wide area and enormous productive facilities over which the general metallurgical conditions were approximately alike. This was due to the predominating influence of the Lake ore supply in the Chicago, Detroit, Cleveland, Buffalo and Pittsburgh districts and to the dependence of these districts on coke made from the rich deposits of coking coal of Pennsylvania, West Virginia, Kentucky and Southern Illinois. This similarity of basic conditions had brought about a considerable uniformity in blast-furnace design and practice for the greater bulk of the output of pig iron made in the States. For this reason the operations and plants located in those territories where the raw material situation was not influenced by dependence upon Lake ores was of particular interest to foreigners in showing how American practice was affected by less favourable or different raw materials. For this reason the writer could have wished that Mr. Haven in his review of what might be termed the subsidiary American iron-producing districts had included the important operation of the Bethlehem Steel Corporation at Sparrows Point, which was essentially based on the employment of imported ores from Cuba and Chile. Also, the author's notes on the iron-manufacturing operations in the Rocky Mountain district might have been supplemented by some reference to the relatively important production of the Colorado Fuel and Iron Co. at Pueblo, where the coking coals of Southern Colorado met the hematite ores emanating from New Mexico, Colorado and Wyoming. It would be interesting if Mr. Haven could supplement the figures for the assembly cost of ironmaking materials given in Table VIII. with data pertaining to the two operations above named.

Mr. Haven might also have given an indication of which among the principal American iron producing districts made the cheapest iron. From the data presented in his paper it would appear that developments in Alabama had at last brought this area into stable and economic production, so that the inherent advantages that it possessed of a low assembly cost of reasonably satisfactory iron-making materials must now result in very favourable overall costs of production, which should be amongst the lowest in the States. Further increase in production in this area would, however, seem to be dependent upon a greater degree of general industrialisation in nearby States creating a larger economically accessible market to the Southern Works, as it must be difficult to compete in the territories served by the Eastern and Middle West producers.

A study of the distribution of furnaces of different sizes given in Fig. 4 in conjunction with the information presented in Table IX. served to show that the average size of furnace unit in the Pittsburgh district was appreciably smaller than that of the average stack in the Chicago district—642 tons per furnace per day as compared with 725 tons. The writer presumed that this was due to the fact that the average age of plants in the Pittsburgh area was greater and that in some large but old-established works the possibilities of enlargement of individual units were less than in the newer and more liberally laid-out plants that made the bulk of the output in the Chicago area. Both those large districts were, however, eclipsed in the average size of furnace operating in Maryland, whilst Pittsburgh was also exceeded by the average productivity of the Detroit stacks. Altogether, it would seem that there were approximately 30 furnaces in the States of 800 tons per day capacity or greater out of a total of 234 listed in Table IX. The writer knew of one or two relatively small steel plants which operated only one very large stack, an example being the Warren plant of the Republic Steel Corporation. He had often wondered what happened to the rest of the works when the single blast-furnace was out for relining and it would be interesting to him if Mr. Haven could say how the disturbance to the heat balance of the works as a whole and of the iron supply to the open-hearth department which must occur for an appreciable period at intervals of  $3\frac{1}{2}$ –4 years was taken care of. How far did this loss offset the operating and capital savings which were claimed to result from the ultra-large unit?

In the section of the paper on gas-cleaning equipment, reference was made to a superposed electric precipitator and gas-washer unit. This design must be regarded as a very real improvement. The simplification that it effected in plant layout was clearly indicated in Fig. 8. In the operating costs for this type of plant given in Table X. there would appear to be a discrepancy in the cost or consumption of water for the primary scrubber and for the precipitator which might be clarified, as these items were amongst the more important factors in operating expense. It would be interesting to know whether the developments in the direct return of flue dust to the furnace which had taken place in Germany and would seem to have well passed the experimental stage there, were likely to influence American practice in the near future. It was claimed that upwards of 90% of the dust content in a gas containing, say, 15 grains of dust per cu. ft. when entering the primary dust-catcher of the furnace, could be extracted in the dust-catcher followed by a pair of cyclone-type extractors, placed in series with each other, and piped directly back to the furnace by using about 3500 cu. ft. of air or cleaned gas per ton of dust as the conveying medium and at an overall cost of 80 pfennigs (say, 10d.) per ton. If this process had received consideration in the States it would be interesting to know at what level it was considered best to inject the flue dust. In Germany a point just

above the bosh seemed now to be most favoured. Further, it would be interesting to learn whether it was considered best to introduce such dust at one place or at several points distributed around the circumference.

Referring to the useful data on American blast-furnace practice given in Tables XII. to XIV., the writer would be glad if Mr. Haven could amplify what is meant by the dry granulation of slag partially adopted in the plant *E*.

Mr. J. J. GHANDY and Mr. E. T. WARREN (Jamshedpur, India) wrote that the author was to be congratulated on his excellent paper. It presented a concise picture, as never before, of the blast-furnace raw-material situation in America.

The author referred to 70-ton ore cars. Actually, the United States Steel Corporation had brought many thousands of tons of ore to Pittsburgh in 90-ton cars during the last few years. At the Edgar Thomson Plant, they had a car-dumper that not only handled this size of railway equipment, but was designed for cars up to a capacity of 120 tons.

The author's proposed 30-ft. furnace was full of interest. It was only fourteen years ago that Mr. J. E. Lose, now operating Vice-President of the Carnegie Illinois Steel Corporation, spoke before the Eastern States Blast Furnace and Coke Oven Association on "The Behaviour of Large Hearth Furnaces." At that time he was operating furnaces with diameters of 21 ft. 6 in. in the hearth. To-day, one spoke of 30-ft. furnaces. Of course, 28-ft. furnaces had been in blast for several years, but their performance had never been outstanding. This was undoubtedly due to insufficient working volume and extremely steep boshes. The lines of Mr. Haven's proposed furnace were excellent. He had kept the ratio between the top area and the big-bell area at about 1.81. As furnaces increased from the old 17-ft. tops to the 18-ft., 19-ft. and 20-ft. tops, this ratio proved satisfactory. But would it be equally satisfactory for a 21-ft. 6-in. top? The other point to remember was that as hearth diameters increased, the tuyeres became farther and farther apart and the lines of gas penetration and stock movement changed. Would this furnace operate as smoothly and with as low a coke rate as a furnace with a hearth 25 ft. 0 in. in dia.? Some day, undoubtedly, the question would be answered.

It would be of interest to those engaged on problems relating to blast-furnace practice if a comparison were presented of the practice of a blast-furnace of the Tata Iron and Steel Company at Jamshedpur, equipped and built on American lines, with those outlined in Mr. Haven's paper. Although the furnace at Jamshedpur was on American lines, the raw materials differed, in that high-ash coke, high-alumina burdens and a high content of iron in the ore were encountered, together with high atmospheric humidity, rising to as much as 13 grains per cu. ft. of air during the monsoon season.





TABLE B.

1	2	3	4	5	6	7	8	9	10	11	12	13	14
Furnace.	Actual Coke Rate, Lb. per Ton of Iron.	Fixed Carbon in Coke, %.	Carbon in Net Coke per Ton of Iron, Lb.	Scrap used per Ton of Iron, Lb.	Carbon Adjust- ment for Scrap at 1200 lb. of Carbon saved per Ton of Scrap. Lb.	Moisture per Cu. Ft. of Blast. Grains.	Carbon Adjust- ment for Humidity Diff. at 37 lb. of Carbon per Grain. Lb.	Slag Volume per Ton of Iron, Lb.	Carbon Adjust- ment for Slag Volume Diff. at 0.164 lb. of Carbon per lb. of Slag. Lb.	Silicon in Pig Iron at 5 lb. of Carbon per 0.01% of Silicon, %.	Carbon Adjust- ment for Silicon Diff. in Iron, Lb.	Total Carbon Adjust- ment except for Iron Content of Ors., Cols. 6 + 8 + 10 + 12.	Iron in Raw Material, %.
A	2009	89.74	1803	223	+ 120	4.10	-66	1350	- 73	1.39	-155	1629	51.90
B	1631	90.50	1476	128	+ 69	2.32*	Nil	850†	+ 8	1.07	+ 5	1558	64.53
C	1659	89.47	1484	29	+ 15	2.32*	Nil	848	+ 9	1.22	- 70	1438	58.70
D	1662	94.21	1566	Nil	Nil	2.32	Nil	900	Nil	1.08	Nil	1566‡	49.90
E	2258	85.80	1937	234	+ 125	3.30	-36	1800	-148	0.97	+ 55	1933	39.80
F	1740	90.03	1567	204	+ 109	2.32*	Nil	1553	-107	1.06	+ 10	1579	55.48
Total.	1846	77.00	1421	9	+ 5	4.93	-96	1066	- 27	1.01	+ 35	1338	60.40

\* Assumed to be similar to Chicago District.

† Calculated from data in author's paper.

‡ All adjustments made to Chicago practice.

Table A gave details of Tata's furnace and its practice for the month of January, 1940.

Studying the practices of the six American furnaces and the Tata Furnace at Jamshedpur, it was found that there was a wide variation in coke practice between these seven furnaces. This, of course, was to be expected. Disregarding the furnace design and the human element, the main reasons for coke variations were the fixed carbon in the coke, the scrap used, the amount of moisture in the air, the slag volume, the composition of the iron produced and the iron content of the ores, sinters, &c., charged. In comparing the fuel rates of various blast-furnaces, it was always well to speak in terms of pounds of carbon in the net coke per ton of iron. In setting up Table B, not only had this been done, but also adjustments had been made in this carbon rate for differences in the scrap consumed, the humidity, the slag volume and the silicon content in the iron. The method of adjustment was open to some criticism, but it was at least equitable for all plants. Plotting these adjusted carbon

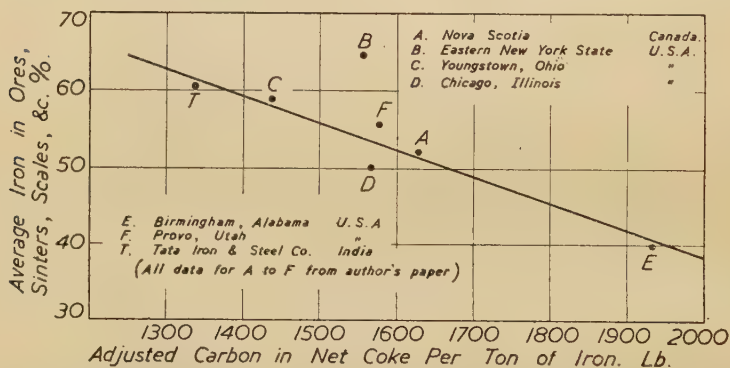


FIG. B.—Relationship between the Percentage of Iron in the Ores, Sintors, &c., Charged to the Pounds of Adjusted Carbon in the Net Coke per Ton of Iron.

figures for each furnace against the percentage of iron in the burden, it would be seen what a marked effect the iron content of the ores had on the coke rate. Fig. B brought out the remarkable closeness of the results attained in the American furnaces in regard to fuel efficiency. The one exception was the *B* plant in Eastern New York State, which, although it had the lowest coke rate of all the six American furnaces, actually showed a higher rate than could be expected with the raw materials that were available. There were two possible reasons for this furnace being out of line. The first was the use of a burden made up of 100% of magnetite ores, and the second was the design of the furnace with its flat 77° bosh angle.

The author's reply had not been received at the time of going to press.

## SECTION II.

# *A SURVEY OF LITERATURE ON THE MANUFACTURE AND PROPERTIES OF IRON AND STEEL, AND KINDRED SUBJECTS.*

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The Editor has been assisted in the preparation of this Survey by R. A. RONNEBECK.





## REFRACTORY MATERIALS

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**Preparation of Crucibles from Special Refractories by Slip-Casting.** J. G. Thompson and M. W. Mallett. (Journal of Research of the National Bureau of Standards, 1939, vol. 23, Aug., pp. 319-326). The authors describe how crucibles up to 300 c.c. in capacity, with thin walls and smooth inner surfaces, can be prepared by a modification of the process of slip-casting, widely used in the ceramic industry. In ceramics the "slip" consists of an aqueous suspension of finely ground clay, which is poured into a plaster-of-Paris mould. As the plaster of Paris absorbs the water from the slip the latter solidifies and shrinks against the mould and the crucible is subsequently dried and fired. In the case of metallurgical crucibles of special refractory materials, the refractory in the finely ground state is moistened with dilute hydrochloric acid.

**Thermochemistry of North Carolina Olivine in the Manufacture of Forsterite Refractories.** R. L. Stone. (Journal of the American Ceramic Society, 1939, vol. 22, Oct., pp. 342-348). The author reports on an investigation of the chemical behaviour of olivine during the production of forsterite refractories. Olivine is an olive-green rock found in North Carolina, and it has the approximate composition: silica 40.1%, alumina 1.0%, ferric oxide 6.7%, lime 0.2%, magnesium oxide 50.5% and alkalis 1.7%.

**A Critical Examination of the Load Test for Refractories.** F. H. Norton. (Journal of the American Ceramic Society, 1939, vol. 22, Oct., pp. 334-336). The author describes the equipment and technique employed for making long-time tests on refractories at high temperatures. The technique is similar to that for making creep tests with metals. He found that a uniform rate of movement under compression is only attained after about 100 hr. have elapsed, so that tests of shorter duration give values much below those which can be applied with safety. The author suggests that a test of 300 or 400 hr. should be applied, for which the time required to take readings is only a few minutes per day if a temperature controller is used; the value of the results obtained from such tests would justify the additional expense as compared with short-time tests.

**A Laboratory Slagging-Test Furnace with a Rotating Burner.** R. K. Hursh. (Journal of the American Ceramic Society, 1939, vol. 22, Oct., pp. 354-357). The author describes a furnace which was specially designed for testing the effects of slags on refractory bricks. This is a vertical cylindrical furnace about 3 ft. high fired by natural gas from a burner which passes down through a 4½-in.-dia. hole in the top. The burner itself consists of three concentric

copper pipes through which primary air, natural gas and secondary air are passed. This burner is suspended within a wrought-iron pipe with a conical hopper at the top to receive the powdered slag, and the lower end of this pipe is bent at  $45^\circ$  to direct the flame and slag against the furnace wall. The slag pipe is rotated at 13 r.p.m. The bricks to be tested are built into the furnace wall, and after the furnace has been brought up to the test temperature the slag feeding is commenced and kept running for about 8 hr., after which the furnace is allowed to cool and the bricks are examined. By using coal-ash slags and adjusting the temperature correctly, the test can be run under conditions similar to those in boiler-house practice and valuable information can be obtained on the washing action of slag flowing over the surface of refractory bricks.

**Sprung-Arch Roofs of High-Temperature Furnaces.** J. S. McDowell. (Blast Furnace and Steel Plant, 1939, vol. 27, June, pp. 592-597; Sept., pp. 947-951; Heat Treating and Forging, 1939, vol. 25, July, pp. 354-359; Sept., pp. 465-469). In the first part of this series the author discusses the materials used in the construction of arched roofs for furnaces operating at temperatures exceeding  $3000^\circ$  F. In the second part he deals with different designs of arches for open-hearth furnaces.

**British Standard Definitions of Heat-Insulating Terms and Methods of Determining Thermal Conductivity and Solar Reflectivity.** (British Standards Institution, No. 874-1939).

## FUEL

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**The Physics of Heat Insulation.** A. W. Smith. (Industrial Heating, 1939, vol. 6, July, pp. 639-644; Aug., pp. 735-740). The author explains the theory of heat transmission by radiation, conduction and convection, and studies the variation in thermal conductivity of a substance at different temperatures, the relation between thermal conductivity, density and elasticity, and finally the conduction of heat in powders and granular materials and through walls.

**Surface Heat Losses from Outside Furnace Walls.** J. G. Coutant. (Heat Treating and Forging, 1939, vol. 25, Sept., pp. 463-464, 469). The author presents a chart showing the rate of heat loss to the surrounding atmosphere from firebrick, aluminium, enamelled and painted surfaces at temperatures from 100° to 900° F., and explains how to calculate the radiant- and convection-heat losses from the walls of industrial furnaces.

**Combustion Control.** M. J. Boho. (Steel, 1939, vol. 105, Sept. 11, pp. 42-45). The author describes a system of control regulators and meters which can be applied to the supply of coke-oven gas, or fuel oil, or tar, to enable a rapid change-over to be made from one fuel to another for soaking pits and reheating furnaces at steelworks. The fuel/air ratio is also automatically controlled no matter which fuel is being used.

**Air Cleaning Fine Coal.** D. H. Davis and V. D. Hanson. (Sixteenth Annual Coal Convention of the American Mining Congress, Apr., 1939; Colliery Guardian, 1939, vol. 159, Sept. 29, pp. 457-461). The authors describe the plant and conditions of operation of the Stump air-flow coal cleaner, which is used by the Pittsburgh Coal Co. for the cleaning of coals smaller than  $\frac{3}{8}$  in. They also discuss the effects of variations in the moisture content of the air, of changing the rate of feed of the coal and of changes in the size ratio of the raw coal on the results obtained.

**Use of Pulverized Coal as Fuel for Open-Hearth Furnace Melting Steel for Castings.** J. P. Kittredge. (American Institute of Mining and Metallurgical Engineers, 1939, Technical Publication No. 1119). The National Malleable and Steel Castings Co. of Sharon, Pennsylvania, has used pulverised coal as a fuel for melting steel in open-hearth furnaces since 1913. In this paper the author describes, with diagrams, one of these furnaces with special reference to the coal-storage bins, the burners and the removable slag pockets. In this process it is most essential that the coal is finely ground, and the pulverising plant must be capable of reducing the coal so that at least 90% will pass through a 240-mesh screen. In conclusion

the author presents tables comparing the costs of using pulverised coal alone, pulverised coal atomised with high-pressure natural gas, and fuel oil.

**Fuel Economy at a Large British Metallurgical Works : Normanby Park (Scunthorpe, Lincolnshire).** C. Berthelot. (*Revue de Métallurgie, Mémoires*, 1939, vol. 36, Aug., pp. 357-372). The author describes and illustrates the Becker coke-oven and by-product plant at the Normanby Park Works of John Lysaght, Ltd., at Scunthorpe, and makes a detailed examination of the coal and coke consumption in relation to the quantities of pig iron, steel and by-products produced at these works.

**The Corby Coke-Oven Plant of Stewarts and Lloyds.** (*Colliery Guardian*, 1939, vol. 159, Sept. 15, pp. 405-408). **Electrical Operation of Coke-Oven Plant.** (*Engineering*, 1939, vol. 148, Sept. 29, pp. 355-357). **Modern Handling Methods in a Coke-Oven Plant.** (*Mechanical Handling and Conveying*, 1939, vol. 26, Oct., pp. 299-302). **Electrical Equipment of Corby Coke-Oven Plant.** (*Industrial Power and the Fuel Economist*, 1939, vol. 15, Sept., pp. 265-268). **Corby Coke-Oven Plant.** (*Coke and Smokeless Fuel Age*, 1939, vol. 1, Oct., pp. 155-158). An illustrated description is given of the coke-oven plant and equipment at the Corby Works of Stewarts and Lloyds, Ltd. There are 113 ovens arranged in three batteries. These are of the Becker cross-regenerative combination type, and each oven measures 40 ft. 8 in. long by 13 ft. high, by 16 in. wide. The charging car, pusher machines and auxiliary machinery are also described.

**Carbonising Properties and Petrographic Composition of High-Splint Bed Coal from Closplint Mine, Closplint Harlan County, Ky.** A. C. Fieldner, J. D. Davis, D. A. Reynolds, W. A. Selvig, G. C. Sprunk and H. S. Auvil. (*United States Bureau of Mines*, 1939, Technical Paper No. 599). This report gives the results of microscopic, physical and chemical examinations and the yield and quality of carbonisation products obtained by carbonising the high-volatile coal from the Closplint Mine, Kentucky, by the Bureau of Mines and American Gas Association method.

**Friability, Slacking Characteristics and Low-Temperature Carbonization Assays of Sub-Bituminous Coals of the Denver (Colo.) Region.** (*United States Bureau of Mines*, 1939, Aug., Report of Investigations No. 3457). Particulars are given of the results of analyses, friability and accelerated weathering tests carried out on the sub-bituminous coals of the Denver district coalfield in Colorado.

**Measurement of Pressures Developed during the Carbonization of Coal.** C. C. Russell. (*American Institute of Mining and Metallurgical Engineers*, 1939, Technical Paper No. 1118). After reviewing various methods of testing the swelling properties of coking coals using specially constructed ovens, the author describes in detail one designed by the Koppers Co. which takes a charge of about 400 lb. of coal, is heated from both sides, and has one movable



wall the movement of which is counter-balanced by suspended weights ; these weights constitute a means of measuring the pressure exerted by the swelling of the coal. He presents data obtained with this oven and compares these by means of graphs with those obtained by H. Koppers and A. Jenkner and by V. G. Altieri.

**Further Work on Swelling Coals.** (Coke and Smokeless-Fuel Age, 1939, vol. 1, Sept., pp. 113-116). Descriptions and drawings are given of the experimental coke-ovens used by the United States Bureau of Mines for testing the swelling properties of coking coals, and the conclusions reached by H. S. Auvil, J. D. Davis and J. T. McCartney are discussed. (*See Journ. I. and S.I., 1939, No. II., p. 255 A*).

**A New Method of Carbonising Coal Blends.** L. M. Sapozhnikov. (Coke and Smokeless-Fuel Age, 1939, vol. 1, Aug., pp. 91-94 ; Sept., pp. 129-131). The author describes a series of experiments, using Russian coals, which had as its object the determination of new methods of producing large pieces of only slightly-fissured coke from mixtures containing limited quantities of coking coals. It is known that a body can be made to rupture under considerably less stress if primary cracks exist at its surface than when such cracks are not present. The author therefore thought it probable that by unevenly distributing the components of a charge of coal in a coke-oven in such a way that the coking coal was concentrated at the walls, and the other coal of lower coking capacity was at the centre where it would be heated more slowly, the properties of the coking coal would be exploited to the full and a stronger coke would be produced. He describes the apparatus he constructed to test this theory on a laboratory and semi-industrial scale, and discusses the crack-formation in specimens of coke produced from charges made up of five layers of different blends of coal.

**Recuperation of Sulphur in Continental Coking Plants.** C. Berthelot. (Coal Carbonisation, 1939, vol. 5, Apr., pp. 57-60 ; Coke and Smokeless-Fuel Age, 1939, vol. 1, Aug., pp. 95-97, 102 ; Sept., pp. 133-134). An English translation of an article which appeared in *Génie Civil*, 1938, vol. 113, Nov. 12, pp. 401-406. (*See Journ. I. and S.I., 1939, No. I., p. 139 A*).

## PRODUCTION OF IRON

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**Reconstruction of the Redbourn Works of Richard Thomas & Company, Limited.** (Iron and Coal Trades Review, 1939, vol. 139, Nov. 3, pp. 597-601). An illustrated description is given of the Redbourn Works of Richard Thomas & Co., Ltd., at which a comprehensive scheme of reorganisation of the coke-oven, blast-furnace and steel plant has recently been completed.

**Rebuilt Blast-Furnace at Workington.** (Iron and Steel, 1939, vol. 13, Oct., pp. 14-16). Some statistics are given concerning the dimensions and operation of a rebuilt blast-furnace at the works of the Workington Iron and Steel Co., Ltd. This furnace now has a production capacity of 3000 tons of pig iron per week. An interesting feature of the furnace is that the whole of the hearth jacket is bricked in, which is a safety measure now advocated by the United States Bureau of Mines.

**The Tennessee Coal, Iron and Railroad Company.** C. Longenecker. (Blast Furnace and Steel Plant, 1939, vol. 27, Aug., pp. 791-794). The author reviews the history of the development of the Tennessee Coal, Iron and Railroad Co., which is now a subsidiary of the United States Steel Corporation.

**Actual Problems in the Production of Pig Iron and the Direct Process of Iron Production.** E. Fornander. (Jernkontorets Annaler, 1939, vol. 123, No. 7, pp. 337-352). (In Swedish). In describing the improvements which have been made to blast-furnace plant and equipment in Sweden in recent years, the author pays particular attention to : (1) The increased diameter of the hearth and the increased height of the tuyeres ; and (2) the improved stoves and the resulting higher temperatures of the blast. He gives brief descriptions of the Tholander stove with horizontal tubes, a Gjers-type stove as modified by Härdén, the Tigerschiöld-Afzelius and the Schack recuperators, and Lindblom's stove. The author also gives some particulars concerning electric-furnace pig iron and compares the consumption and production data of the Elektro-metall and the Tysland-Holes furnaces. He concludes with some notes on the results so far achieved with the Rennerfelt-Kalling direct process at the three plants at Fagersta, Imatra and Hagfors. (See Journ. I. and S.I., 1939, No. II., p. 190 A).

**Comments on Southern Blast-Furnace Practice and some of its Peculiarities.** J. E. Urquhart. (Iron and Steel Engineer, 1939, vol. 16, Sept., pp. 72-80). In describing the blast-furnace practice of the Birmingham district of Alabama, the author points out that, owing to the close proximity of the ore, limestone and coke deposits, the mild climate and low rates of wages, there had been no great

incentive to reduce costs, as there was in the north, but more recently wages had risen and other changes had led to the development of more economic methods of working. The author gives details of these improvements, which include crushing the ore to smaller sizes, sintering the fines, crushing and grading the coke, reducing the moisture in the blast and using higher blast temperatures.

**Effect of the Volume and Properties of Bosh and Hearth Slag on Quality of Iron.** G. E. Steudel. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1108: Metals Technology, 1939, vol. 6, Sept.). The author discusses the slag problems encountered in the working of the blast-furnaces at the South Works of the Carnegie-Illinois Steel Corporation.

**Effect of the Solution-Loss Reactions on Blast-Furnace Efficiency.** P. V. Martin. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1107: Metals Technology, 1939, vol. 6, Sept.). The author studies the thermochemistry of the reactions which occur in the blast-furnace with particular reference to the theories which are not in agreement with Gruner's theorem. This theorem, published in 1870, was that in the ideal blast-furnace the reduction of the ore is effected by the carbon monoxide being transformed into carbon dioxide without the consumption of solid carbon. The reactions which violate this principle are known as "solution-loss reactions."

**Possibilities of Utilising the Blast-Furnace Slags Arising from the Acid-Smelting Process.** G. Mussnug. (Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns, 1939, vol. 7, June, pp. 67-76). The possibilities of making use of the large quantities of acid slag now available in Germany as a result of the smelting of low-grade ores are examined. This paper also appeared in Stahl und Eisen, 1939, vol. 59, Aug. 3, pp. 889-894. (See Journ. I. and S.I., 1939, No. II., p. 258 A).

**A Melting Furnace for Ferro-Manganese.** E. G. Fiegehen. (Foundry Trade Journal, 1939, vol. 61, Aug. 31, pp. 153, 156). The author describes a furnace, which may be fired by oil or gas, designed for melting 400 lb. of ferro-manganese in four plumbago crucibles. He reproduces the heat demand and heat input calculations for oil firing, which show a consumption of 33.7 gallons of oil per hr., using oil with a calorific value of 18,500 B.Th.U. The melting time for the above quantity is approximately 3 hr.

**Preparation of High-Purity Iron.** J. G. Thompson and H. E. Cleaves. (Journal of Research of the National Bureau of Standards, 1939, vol. 23, July, pp. 163-174). The authors describe a method of preparing iron of high purity in the form of 1-lb. ingots and the analytical tests made on these ingots. The method consisted of reducing purified iron oxide to sponge iron, melting the sponge iron, remelting under hydrogen, and cooling *in vacuo*. The ingots were examined for the presence of fifty-five possible impurities,

and the number which could be identified in individual ingots ranged from six to nine. The total impurity in each ingot was in most cases less than 0.010%.

**A Pig-Iron Grading Scheme.** (Foundry Trade Journal, 1939, vol. 5, Oct. 5, pp. 227-228). An abridged version is given of the recommendations of the British Cast Iron Research Association for the grading of pig iron. This scheme provides a series of grades into which the various types of British pig and refined irons can be arranged on a basis of chemical composition; its object is to indicate to users of pig and refined irons what compositions are normally available, and to give the limits of composition for each grade. In this grading scheme each class of pig iron is designated by a capital letter, *e.g.*, hot-blast by *H*, basic by *B*, cold-blast by *C*, and refined by *R*, and this letter is followed by a combination of letters and numbers which is indicative of the limits of analysis.

**The "Iron Bellows" of Duddon Furnace, Cumberland.** J. N. Mart. (Transactions of the Newcomen Society, 1937-1938, vol. 18, pp. 93-98). The author gives a description of the blowing mechanism used at the Duddon Furnace in Cumberland. This furnace was built about 1736 and stopped working in 1867. The "iron bellows" consisted of two cast-iron cylinders 5 ft. 2 in. in dia., 3 ft. 4 in. deep, with iron pistons packed with leather. The pistons were operated by cams or wipers on a 27-in.-dia. wooden shaft driven by a water-wheel. Air was admitted through a valve at the bottom of the cylinder and expelled through a sheet-iron pipe to the tuyeres.



## FOUNDRY PRACTICE

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**Modification of the Properties of Cast Iron in the Ladle.** A. J. N. Smith. (Bulletin of the British Cast Iron Research Association, 1939, vol. 6, No. 2, pp. 37-40). The author reviews the methods by which the properties of cast iron can be modified by means of special treatment in the ladle immediately prior to casting. The methods reviewed include those for increasing and reducing the chill and for increasing the strength properties. In conclusion the author describes the methods of making additions to the ladle and presents a table showing the maximum amounts of nickel, copper, chromium, molybdenum and silicon which can be added and the percentage lost by oxidation.

**Influence of Graphite Ladle Additions on the Mechanical Properties of Gray Cast Iron.** A. H. Dierker, R. P. Schneider and H. H. Dawson. (Ohio State University Engineering Experiment Station Reports, 1939, vol. 8, July, No. 4, pp. 3-6). The authors report on some experiments made with the object of determining the effect of adding graphite to grey cast iron in the ladle on the mechanical properties as well as on the depth of chill. The results showed that adding graphite to the ladle reduces the chilling tendency and that the mechanical properties of the castings are not affected in any important degree by small additions of graphite at the cupola spout.

**Modern Equipment for Clean Annealing Malleable Iron.** W. F. Ross. (Industrial Heating, 1939, vol. 6, Aug., pp. 683-692). The author describes a 340-kW. pusher-type furnace and an 860-kW. roller-hearth continuous malleablising furnace. This furnace equipment was previously described in Heat Treating and Forging, 1939, vol. 25, Apr., pp. 195-199. (See Journ. I. and S.I., 1939, No. II., p. 70 A).

**Notes on Steel Foundry Practice.** S. Leetch. (Institute of British Foundrymen: Foundry Trade Journal, 1939, vol. 61, Sept. 14, pp. 182-183; Sept. 21, pp. 197-198; Sept. 28, pp. 214-216). The author describes the practice at a steel foundry making about 200 tons of castings per week. He deals mainly with the moulding and the respective applications of oil-, green- and dry-sands and of "compo" moulding materials made up in accordance with the recipe found most suitable for a particular type of casting.

**Steel Castings in Aircraft.** A. Finlayson. (Iron and Steel, 1939, vol. 13, Oct., pp. 11-13, 16). The author describes some of the casting, heat-treatment and testing processes used in the manufacture of the copper-silicon steel castings which form part of the landing gear of the large aeroplanes manufactured by the Boeing Aircraft Co.

**Cast Soil Pipe Centrifugally.** H. H. Farr. (Foundry, 1939, vol. 67, Sept., pp. 24-26, 72-74). The author describes the procedure at a large American foundry where 6 in.-dia. cast-iron sewage pipes are made by the centrifugal process.

**Contribution on the Manufacture of Cast Machine Parts.** C. W. Pfannenschmidt. (Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns, 1939, vol. 7, Aug., pp. 115-143). In his discussion of the causes and prevention of wasters in the manufacture of grey-iron machinery castings the author deals first of all with shrinkage in the liquid phase and during solidification, and makes recommendations as to the dimensions and position of the risers relative to the mould. He then discusses in turn the influence of wall-thickness on the hardness and strength of castings, static and dynamic methods of testing, the fatigue strength in relation to the condition of the surface and the wall-thickness, the design of moulds and cores, the mounting of cores, and the design of hollow and ribbed castings. In conclusion he considers welded *versus* cast structures.

## PRODUCTION OF STEEL

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**Note on the Iron and Steel Works at Corby (England).** T. P. Colclough and R. P. Lemoine. (*Revue de Métallurgie, Mémoires*, 1939, vol. 36, July, pp. 326-334). After discussing the economic factors which led to the building of the iron and steel works of Stewarts and Lloyds, Ltd., at Corby and the metallurgical principles applied there, the authors present an illustrated description of the various departments and the plant.

**Iron and Steel Production in South Wales.** (*Metallurgia*, 1939, vol. 20, Sept., pp. 166-172). Brief descriptions with numerous illustrations are presented of the South Wales works of Richard Thomas and Co., Ltd., Guest, Keen and Nettlefolds, Ltd., the Whitehead Iron and Steel Co., Ltd., and Guest Keen Baldwins Iron and Steel Co., Ltd.

**The East Moors Works of Guest, Keen, Baldwins Iron and Steel Co., Ltd.** (*Iron and Steel*, 1939, vol. 12, Sept. 25, pp. 824-827). An illustrated description is given of the East Moors Works of Guest Keen Baldwins Iron and Steel Co., Ltd., which is an excellent example of a modern balanced plant in which the only fuels used are blast-furnace and coke-oven gases. The plant comprises coke-ovens, blast-furnaces, open-hearth shop and rolling mills.

**Steel Production.** (*Machinery*, 1939, vol. 54, Sept., pp. 762-764). An illustrated description is given of the furnaces, forge and grinding shops and heat-treatment plant at the works of Hall and Pickles, Ltd., Manchester. The melting plant consists of two 12-cwt. and one 2-cwt. H.F. electric furnaces. The products consist almost entirely of high-speed tool steels; first-grade cast steels; alloy, stainless and heat-resisting steels.

**Actual Problems of Steel Production in Sweden.** S. von Hofsten. (*Jernkontorets Annaler*, 1939, vol. 123, No. 7, pp. 353-365). (In Swedish). After presenting some graphs and tables illustrating the growth of the production of steel in Sweden and the percentages of the total production made by the Bessemer, open-hearth and electric-furnace processes, the author surveys some of the improvements which have taken place and the problems still to be solved with regard to refractories, ingot moulds, the use of aluminium as a deoxidiser, hydrogen in steel and the grain size of steel.

**Contribution to the Problem of Nitrogen in Basic Bessemer Steel.** W. Bøddeker. (*Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns*, 1939, vol. 7, Aug., pp. 145-146). The author studied the relationship between the age of the lining of a basic Bessemer converter and the nitrogen content of the steel produced. With each successive renewal of the bottom the nitrogen content of the steel decreased, but for any given lining the nitrogen

content increased with each successive blow. The author suggests that the cause of this phenomenon is connected with the increase in the volume of the converter brought about by the cutting action of the blast on the bottom and on the lining.

**Instrument Control of Open-Hearth Furnaces.** E. T. W. Bailey. (Transactions of the Canadian Institute of Mining and Metallurgy, 1939, vol. 42, pp. 397-405). After pointing out the factors which render the application of instruments more difficult to open-hearth furnaces than to other plant such as boilers, the author describes the instruments used in connection with the operation of the No. 14 open-hearth furnace at the Hamilton Works of the Steel Company of Canada, Ltd. This furnace was completed in 1937. The author describes two classes of instruments, viz., those that indicate, record or integrate, but do not control, and those which control. He points out how the consumption of heat per gross ton of ingots produced has decreased during the last ten years, a reduction to which the use of instruments has made an important contribution.

**Some Fundamental Factors in the Control of Steel-Making.** J. White. (Metal Treatment, 1939, vol. 5, Autumn Issue, pp. 101-107). The author discusses the part played by the slag in the open-hearth process. He deals especially with the composition, constitution and melting point of acid and basic slags, the equilibrium diagram for the iron-oxygen system, the iron-oxide equilibrium in liquid slags and the gas-slag-metal relation in the furnace.

**Production Research in Iron and Steel—Its Importance and Value.** H. T. Hildage. (Iron and Steel, 1939, vol. 13, Oct., pp. 7-10). By "production research" the author means the observation, under working conditions and in minute detail, of every operation, process and piece of equipment, always having in mind the passage of time and the rate of working. In such studies each operation is analysed into its elements, each element is scrutinised as to its utility, and the time it takes is measured. Having thus defined "production research," the author gives examples of how this research can be applied in a melting shop, a rolling mill and at soaking pits, with the object of increasing the rate of production and reducing costs. The examples cited have resulted in the discovery and removal of delays and the reduction of costs without in any way "driving" the men or increasing the speed of machinery.

**The Series Iron-Oxides/Silica.** W. J. Crook. (Journal of the American Ceramic Society, 1939, vol. 22, Oct., pp. 322-334). The author reviews his own work on the general series  $\text{FeO-Fe}_2\text{O}_3\text{-SiO}_2\text{-CaO(MgO)}$  as related to slags produced in steelmaking, in which twelve quasi-quaternary mineral systems were established, and describes a new investigation made with the object of checking the earlier findings and of exploring several regions of the quaternary diagram in which only a few samples had previously been investigated. In this investigation he studied the system iron-oxides/silica by preparing melts with and without the presence of metallic iron.



He found that when iron oxide and silica are heated to  $1600^{\circ}\text{C}$ . or higher in a siliceous crucible, the resulting slag consists essentially of tridymite and magnetite, the latter having a composition approaching  $\text{FeO} \cdot \text{Fe}_2\text{O}_3$ , the affinity of  $\text{Fe}_2\text{O}_3$  for  $\text{FeO}$  being so strong that little or no  $\text{FeO}$  is able to unite with  $\text{SiO}_2$  to form fayalite or other silicate. This condition is very different from that existing when iron crucibles are used, for in such case large quantities of ferrous oxide are formed which are much in excess of that required to unite with ferric oxide to produce magnetite. His study of these slags draws attention to the fact that ferric oxide has a much greater affinity than silica for ferrous oxide. One of his experiments was made to find out whether, once an iron-oxide/silica slag had been formed in an iron crucible, its composition would be changed by remelting in a siliceous crucible. This showed that no important change occurred; there was some increase in  $\text{Fe}_2\text{O}_3$  and a small pick-up of silica from the crucible. It is apparent therefore that, once fayalite has formed (in the presence of metallic iron), remelting with no iron present does not appreciably oxidise this silicate.

**The Series Iron-Oxides/Lime.** W. J. Crook. (Journal of the American Ceramic Society, 1939, vol. 22, Oct., pp. 313-322). There is a considerable divergence of opinion recorded in the literature concerning the compounds formed between iron oxide and lime, and one of the objects of the investigation here reported was to determine, if possible, whether the presence of metallic iron during melting is responsible for the production of the triferite. The author concludes that when mixtures of iron oxide and lime are melted under oxidising conditions in contact with metallic iron, a ternary system between  $\text{CaO}-\text{FeO}-\text{Fe}_2\text{O}_3$  prevails and the compound formed between lime and ferric oxide has the composition  $3\text{CaO} \cdot \text{Fe}_2\text{O}_3$  with the possible exception of melts containing somewhat less than 10 mol. % of  $\text{CaO}$ . He also believes that in somewhat ring the "mineralogy" of basic slags in steelmaking, the ternary system  $\text{CaO}-\text{FeO}-\text{Fe}_2\text{O}_3$  should be substituted for the binary system  $\text{CaO}-\text{Fe}_2\text{O}_3$ , which has been generally used in the past.

**On the Macroscopic Structure and Solidification of Steel Ingots.** L. Bruno. (Revue de Métallurgie, Mémoires, 1939, vol. 36, July, pp. 335-354). The author describes the manufacture of steel for making semi-hard rods for reinforced concrete. An electric furnace or a 25-50-ton basic open-hearth furnace is used, from which ingots of 2-3 cwt. are cast. He considers the factors affecting the formation and distribution of blow-holes in rimming-steel ingots, in particular the action of the deoxidants, and differentiates between spherical blow-holes about 5 mm. in dia. situated about half-way between the surface and the longitudinal axis of the ingot, and an elongated form of blow-hole up to 30 mm. in length situated nearer the surface.

## FORGING, STAMPING AND DRAWING

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**Machine Forging of Shells.** (Machinery, 1939, vol. 55, Oct. 12, pp. 25-28). Descriptions are given of some American machines for the upset-forging of shell bodies. The process employs the "internal displacement" or "progressive deep piercing" principle, which, in conjunction with machines of rigid design and accurate alignment, enables forgings to be turned out at a rapid rate to close tolerances. No special auxiliary equipment is necessary, so that many forging machines used for commercial production can be converted for shell forging without delay in an emergency. It also follows that machines installed for shell production become available for ordinary commercial uses when the emergency is passed. With these machines the shape and surface of the pierced hole are of such accuracy and smoothness that boring and reaming are unnecessary, the only operation in the cavity being that of shot-blasting.

**Shell Manufacture in America.** (Machinery, 1939, vol. 55, Oct. 5, pp. 1-4). A description, with numerous illustrations, is presented of the machinery and processes employed for making shells at the Artillery Division of the Frankford Arsenal, Philadelphia.

**Drop Forging Stainless Alloys.** R. W. Thompson. (Iron Age, 1939, vol. 144, Aug. 3, pp. 31-34). The author discusses the points requiring careful attention in the drop-forging of chromium and chromium-nickel steels and Monel metal.

**Combined Shell-Forging and Drawing Press.** (Engineering, 1939, vol. 148, Aug. 4, pp. 136-137). A description is given of a machine in which the two processes of forging and drawing a billet to make a shell are carried out. In this machine the concentricity of the hole in the shell body is ensured automatically. The forgings are produced from square or gothic billets in two operations, the first consisting of piercing and forming the rough forging, and the second in drawing this forging to the required diameter and length, using one, two, three or four drawing dies, as may be necessary. The forging and drawing operations are both effected with one stroke, and only one heat is required.

**Bolt Making in Scotland.** A. P. Newall. (Wire and Wire Products, 1939, vol. 14, Sept., pp. 461-463). The author gives an account of the plant and processes employed by A. P. Newall and Co., Ltd., of Glasgow in the manufacture of wire and bolts to special specifications. The products include "Newall Hitensile" and "Newalloy" heat-treated bolts, which have tensile strengths of 45-55 and 65-75 tons per sq. in., respectively.

**Some Practical Notes on High-Speed Steel Forgings.** W. H. Wills. (American Society for Metals, Oct., 1939, Preprint No. 4). After a brief discussion of the microstructure of high-speed steel, the author describes the manufacture of forged cutting tools of this material. He compares cutters made by forging with those made from bar stock without forging, and shows that when the diameter exceeds about 4 in. the forged cutters are the better.

**Die Design and Construction.** (Machinery, 1939, vol. 54, July 13, pp. 469-471; Sept. 14, pp. 729-732; vol. 55, Oct. 19, pp. 57-60). The design and construction of compound dies which perform simultaneously the operations of blanking and piercing are dealt with in the first two of these articles, whilst in the third the progressive type of die, in which the two operations take place in two separate stages, is discussed.

**Drawing Die Troubles.** C. W. Hinman. (Machinist, 1939, vol. 83, Oct. 14, pp. 683-685). The author discusses difficulties which arise in the drawing of small sheet-metal articles, in particular the wrinkles and cracks caused by incorrect punch and die radii.

**Drawing Dies.** C. W. Hinman. (Machinist, 1939, vol. 83, Sept. 23, pp. 634-636). The author explains the theory of the flow of metal in the drawing of shallow and deep cups from blanks.

**Tools for Deep-Drawing and Pressing.** J. D. Jevons. (Metal Industry, 1939, vol. 55, July 7, pp. 3-6; July 21, pp. 59-62; Sept. 8, pp. 217-220; Oct. 6, pp. 309-313; Oct. 13, pp. 331-334; Oct. 20, pp. 355-357). In the first two parts of this series of articles on the tools and dies for deep-drawing and pressing, the author considers first the desirable properties of tool materials and secondly the materials themselves. The particular properties discussed are machinability and resistance to plastic deformation, abrasion, scoring and fouling. The materials used include carbon steels; low-alloy, high-alloy, case-hardened and chromium-plated steels; plain and alloy cast iron; and soft materials such as some of the non-ferrous metals and alloys, wood and rubber. Of particular interest is graphitic steel; this is made in an electric furnace and contains about 1.5% of carbon with 1% of silicon added to render the carbide unstable and capable of being partially decomposed into graphite and ferrite by suitable annealing.

**Researches on the Deep-Drawing Process.** (Metallurgist, 1939, vol. 12, Aug., pp. 57-61). An abridged account is given of S. Fukui's investigation of the forces required to press cups from flat discs by the deep-drawing process. A full account of this work appeared in Scientific Papers of the Institute of Physical and Chemical Research, Tokyo, 1938, vol. 34, Oct., Part III., pp. 1422-1527. (See Journ. I. and S.I., 1939, No. I., p. 219 A).

**The Testing of Sheet Metal Destined for Deep Drawing and Pressing.** J. D. Jevons. (Sheet Metal Industries, 1939, vol. 13, Sept., pp. 1145-1153). The conclusion of a series of articles (see Journ. I. and S.I., 1939, No. II., p. 265 A). The author considers

first various methods of interpreting the results of tensile tests on specimens of sheet metal. He demonstrates the differences (a) between "actual" stress-strain curves in which the stress values are expressed as stress per unit area of the original cross-sectional area of the unstrained test-piece, and "true" stress-strain curves in which the stress at any stage in the test is expressed in terms of the true cross-sectional area of the specimen at that stage; and (b) between stress-elongation curves in which the elongation is shown as the average percentage elongation, and those in which it is shown as the percentage reduction in area calculated from measurements made throughout the test of the smallest diameter at any position on the test-piece. The author next describes the wedge-drawing test in its original form as devised by Sachs and modifications of it, and from this proceeds to discuss attempts to make high-speed cupping tests in which the tests are carried out at speeds comparable to those normally used in the press shop. In conclusion he outlines a scheme for routine testing and discusses the training of the laboratory personnel.

**Crossley's Continuous Wire Drawer.** (Wire Industry, 1939, vol. 6, Sept., p. 615). Particulars are given of a new four-hole continuous wire-drawing machine with 22-in.-dia. water-cooled blocks recently placed on the market by George Crossley, Ltd., Cleckheaton.

**Making Wire Rope.** R. B. Whyte. (Steel, 1939, vol. 105, July 24, pp. 44-48, 65). The author describes and illustrates the layout, machinery and patenting furnaces at the wire rope works of the Macwhyte Co., at Kenosha, Wisconsin.

**Steel Wire Ropes.** H. D. L. Lloyd. (Transactions of the Liverpool Engineering Society, 1939, vol. 60, pp. 115-130). The author describes and illustrates the constructions of steel wire ropes for mining, shipping and engineering purposes and explains some methods of calculating the ratio of the static load to the breaking load under various conditions of service.



## ROLLING-MILL PRACTICE

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**Phenolic Plastic Applications in the Steel Industry.** H. F. Horne. (Iron and Steel Engineer, 1939, vol. 16, Sept., pp. 66-69). The applications of phenolic synthetic resin materials in steelworks which the author describes in this paper include the coverings of rollers which hold down steel strip in pickling baths, coverings for tension rolls, guide boxes in continuous strip mills which are frequently covered with water spray, and mill bearings made of laminations of woven fabric impregnated with synthetic resin.

**Greases in Every Steel Mill.** H. D. Kolb. (Blast Furnace and Steel Plant, 1939, vol. 27, Sept., pp. 939-942). After describing the characteristics of lime-base, soda-soap and aluminium-soap greases and some methods of testing them, the author considers the factors influencing the selection of a suitable grease for various rolling-mill applications.

**Castle Works and Rolling Mills of Guest, Keen & Nettlefolds, Limited, Cardiff.** (Iron and Coal Trades Review, 1939, vol. 139, Oct. 20, pp. 529-537). A complete account with numerous illustrations is presented of the new rolling mills of Guest, Keen & Nettlefolds, Ltd., Cardiff, where strip, bars, rods, wire and nails are produced.

**Hot-Strip and Merchant Bar Mills at Guest, Keen & Nettlefolds.** (Iron and Steel, 1939, vol. 12, Sept. 25, pp. 831-833). The 10-in. hot strip and merchant bar mill at the Cardiff works of Guest, Keen & Nettlefolds, Ltd., is described in this article. This mill comprises sixteen two-high stands, seven of which are roughing stands, two intermediate stands, two looping stands and five finishing stands.

**This Section Rolling Machine is British.** (Sheet Metal Industries, 1939, vol. 13, Oct., pp. 1233, 1240). An illustrated description is given of a machine for rolling sections for aircraft purposes in aluminium alloy or light-gauge steel. The machine has eight pairs of rolls 6 in. in dia. placed horizontally with 11 in. between each pair. It is driven by a 12½-h.p. motor. The machine has been designed to produce even quite complicated sections in one pass.

**Ebbw Vale—The Works of Richard Thomas & Co., Ltd.** (Iron and Steel, 1939, vol. 12, Sept. 25, pp. 834-838). A brief outline is given, with numerous illustrations, of the plant and processes at the steelworks and rolling mills of Richard Thomas & Co., Ltd., Ebbw Vale.

**The Whitehead Iron and Steel Co., Ltd.** (Iron and Steel, 1939, vol. 12, Sept. 25, pp. 833-834). Some particulars are given of the Courtybella Works of the Whitehead Iron and Steel Co., Ltd., a company formed in 1903 which claims to be the first in

England to adopt the continuous rolling process. The plant comprises a 12-in. continuous hot strip and hoop mill, an 8½-in. semi-continuous rod and bar mill, a 12-14-in. semi-continuous bar and strip mill and a number of cold rolling mills.

**The Most Modern Mill in the World.** (Iron and Steel Engineer, 1939, vol. 16, Sept., pp. C-1-C-25). A full description, with numerous illustrations, data sheets and a blue-print plan, is presented of the Irvin steelworks and rolling mills of the Carnegie-Illinois Steel Corporation.

**Cold Rolling of Stainless Steel.** (Iron and Coal Trades Review, 1939, vol. 139, Oct. 27, pp. 576-577). A description is given with several illustrations of the recently erected rolling mill at the works of Darwins, Ltd., Sheffield. The mill consists of two four-high stands and a two-high finishing stand, and is intended for the cold-rolling and finishing of stainless steel strip.

**The Newport and South Wales Tube Co., Ltd.** (Iron and Steel, 1939, vol. 12, Sept. 25, pp. 828-830: Iron and Coal Trades Review, 1939, vol. 139, Oct. 27, pp. 571-572). After a brief account of the history of the Newport and South Wales Tube Co., Ltd., which in 1936 took over the works of the British Mannesmann Tube Co., Ltd., an illustrated description of the plant is presented. In the tube-mill buildings there are two reheating furnaces, a rotary piercer and two pilger mills.

**Sheet and Tube's New Mill Goes Into Operation.** W. C. Kernahan. (Blast Furnace and Steel Plant, 1939, vol. 27, Sept., pp. 929-933). An illustrated description is given of the recent extensions to the Indiana Harbor Works of the Youngstown Sheet and Tube Co. These include a new 46-in. blooming mill, the enlargement of several soaking pits, new hot and cold strip mills, and new pickling and tinning equipment.

## HEAT TREATMENT

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**Three Methods of Gas Carburizing.** W. A. Darrah. (Metal Progress, 1939, vol. 36, Aug., pp. 149-151). The author considers some methods of controlling the formation of carbon deposit on articles in gas-carburising furnaces. These methods may be classified in three groups—*viz.*, those designed to remove the carbon after formation, those which limit the formation of the carbon deposit and those which prevent its formation. Exponents of the first process advocate the formation of soot on the work as soon as practicable after it enters the furnace and then the supply of an oxidising atmosphere which will burn it off, but the author does not recommend this method. Pertaining to the second group is the technique of circulating a "carrier" atmosphere through the furnace to which precise amounts of carburising gases such as methane and propane are added; this process requires very accurate control of the time and temperature cycles and the composition of the atmosphere. The method favoured by the author belongs to the third group, and it employs the principle of first heating the carburising atmosphere in contact with a metal or catalyst which will cause the free or unstable carbon to be precipitated, and then passing the stabilised gas over the charge, which is kept at a lower temperature than that of the gas. A carburising plant working on this principle on a commercial scale has been previously described in an article entitled "A Practical Muffleless Carburizing Furnace" in Metal Progress, 1938, vol. 34, Dec., pp. 678-683. (See Journ. I. and S.I., 1939, No. I., p. 223 A).

**Hardening Gear Teeth.** D. Vandevate. (Steel, 1939, vol. 105, Sept. 18, pp. 64-66, 111). The author describes and illustrates some machines specially designed for the flame-hardening of the teeth of large gear wheels, in which the burners of the oxy-acetylene torches are moved by hydraulic machinery.

**Flame Hardening Rollers and Roller Paths.** R. L. Spaulding. (Welding Journal, 1939, vol. 18, Sept., pp. 513-515). The author describes the technique employed in the flame-hardening of the surfaces of rollers and the teeth of crane paths.

**Flame Hardening Small Parts.** T. A. Frischman. (Heat Treating and Forging, 1939, vol. 25, Sept., pp. 445-446, 458). The author briefly describes the technique of flame-hardening as applied to small parts of motor-cars. In some cases the heated surface is cooled by a blast of air, and in others, where the area of the surface to be hardened is small, the mass of the metal absorbs the heat sufficiently rapidly.

**New Method of Selective Hardening.** R. S. Minarik. (Heat Treating and Forging, 1939, vol. 25, Aug., pp. 377-378). The author describes the development of a simple process of selective hardening which can be applied for such purposes as the hardening of the centre portion of the face of a hammer. In the example described one electrode of a resistance-type rivet heater was clamped round the face of the hammer and the other electrode was placed in contact with the centre of the face; on applying the current the temperature at the centre rose rapidly and that of the outer area more slowly; on quenching, an ideal condition of a hard centre backed by softer material was obtained.

**Introductory Study of the Nitriding of Hardened High-Speed Steel by the Use of Molten Cyanides.** J. G. Morrison and J. P. Gill. (American Society for Metals, Oct., 1939, Preprint No. 3). The authors discuss in detail the process of surface-hardening high-speed steel by immersion in a molten cyanide bath, dealing with the subject under the following headings: (1) The composition of the nitriding bath; (2) the chemical reactions that take place; (3) the effective life of the solution; (4) the contamination of the bath with particular reference to nickel; (5) the galvanic characteristics of the bath; (6) the nitrogen content of the steel at different depths; (7) the hardness of the nitrified surfaces; (8) the microstructure of the nitrified steel; and (9) the nature and appearance of the surface after immersion. In an appendix the authors describe a method of determining the nitrogen content at successive depths from the surface, increasing by 0.0001 in. at a time.

**The Influence of Alloying Elements on the Scaling and Decarburisation of Steel.** (Metallurgist, 1939, vol. 12, Oct., pp. 73-75). It is pointed out that a comparison of the scaling properties of any two steels should always be made with reference to the same temperature and the same oxidising atmosphere. With these limitations in mind the results of H. Schrader's experiments on the influence of alloying additions on the scaling and decarburisation of steel are discussed. (See Stahl und Eisen, 1939, vol. 59, Apr. 20, pp. 473-482; Journ. I. and S.I., 1939, No. II., p. 91 A).

**Rate of Oxidation of Steels as Determined from Interference Colors of Oxide Films.** D. J. McAdam, jun., and G. W. Geil. (Journal of Research of the National Bureau of Standards, 1939, vol. 23, July, pp. 63-93). The authors report on their investigation, by the observation of temper colours, of the relationships between the thickness of oxide films on steel, the temperature and the time during which the specimens are kept at given temperatures, and they present the results obtained in a series of graphs. A wide variety of carbon and alloy steels was examined. They found that the relation between temperature and time for a constant film thickness, when plotted with logarithmic co-ordinates, is linear. The variation of film thickness with time at constant temperature, when plotted with logarithmic co-ordinates, gives a curved line.



The slope of this line increases with film thickness, and the line approaches a sloping asymptote. For constant oxidation time, the relation between film thickness and absolute temperature, when plotted with logarithmic co-ordinates, also gives a curved line; from these curves it is seen that the accelerating influence of temperature on the rate of oxidation (for constant oxidation time) dominates the retarding effect of increasing film thickness. In their discussion of the relationship between the rate of oxidation and the constitution and physical properties of the oxide films the authors show that the rate of oxidation depends on the oxygen-concentration gradient in the film, and on the diffusional conductivity of the oxide.

**The Effect of Carbon Content on the Rate of Oxidation of Steel in Air at High Temperatures.** C. A. Siebert. (Transactions of the American Society for Metals, 1939, vol. 27, Sept., pp. 752-757). The author studied the effect of the carbon content on the oxidation of steel in the temperature range 1700-2100° F. He found that all of the carbon steels investigated had a critical region in the temperature/scale-formation curve at which the amount of scale commenced to decrease as the temperature increased. This did not apply to Armco iron, which showed a continuous increase in the amount of scale. This difference in behaviour the author attributes to the decarburisation of the steel and its effect on the chemical composition of the scale formed.

**The Process of the Attack of Metals at High Temperatures.** G. Valensi. (Corrosion Conference, Paris, 19-24 Nov., 1938: *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 385-392). The author studies the theory of the formation of oxides on metals at high temperatures and the influence of the character of oxide on the rate at which scaling proceeds.

**Heat Treatment of Materials.** E. K. Gadd. (Journal of the Institution of Production Engineers, 1939, vol. 18, Aug., pp. 322-333). After explaining a simple form of equilibrium diagram for bismuth-tin alloys, the author applies the principles to an explanation of the iron-carbon diagram. In conclusion he discusses the theory of the heat treatment of steel, explaining the changes in structure which are brought about by such treatment by reference to the iron-carbon diagram.

**New Equipment Installed for Heat Treating Truck Propeller Shafts.** W. F. Ross. (Heat Treating and Forging, 1939, vol. 25, Sept., pp. 452-454). The author describes a heat-treatment plant at an American automobile works for the hardening of motor-lorry propeller shafts. The plant comprises a gas-fired hardening furnace in which the shafts are heated to 1550° F., mechanical oil-quenching equipment and a gas-fired drawing furnace for heating the shafts to 1050° F.

**The Theory and Practice of the Heat Treatment of Armour-Piercing Shells.** M. J. Obremski. (*Wiadomosci Techniczne Uzbrow-*

jenia, 1938, July, p. 285 : *Mémorial de l'Artillerie Française*, 1939, vol. 18, No. 70, pp. 391-410). In the first part of this paper the author considers the relationship of the  $Ac_1$ - $Ac_3$  temperature interval of a steel to the hardness of that steel and applies this to the problem of ascertaining the correct heat-treatment temperatures for the production of the required variation in the hardness of armour-piercing shells. In the second part he describes the technique of heating and quenching to be followed in order to comply with the conclusions arrived at in his theoretical discussion.

**Drill Steels and Drills.** L. Sanderson. (*Colliery Engineering*, 1939, vol. 16, Aug., pp. 296-298, 301; Sept., pp. 350-352; Oct., pp. 382-383). In the first part of this series the author discusses the design and manufacture of hollow steel drilling bits for mining purposes. He describes the different methods of making the hole down the centre of the bit and stresses the importance of the inner surface being as smooth as possible. He compares machine-made with hand-made bits, showing that the former are superior. In the second part he describes the technique of heat treatment for the head and shank of the bit, using either the blacksmith's forge or an oil-fired furnace. In Part III. the author describes and illustrates six distinct types of bit which can be purchased ready for use and gives some advice on drilling operations.

**Re-Forging and Heat Treatment of Jackbits.** F. G. Burns. (*Proceedings of the Australasian Institute of Mining and Metallurgy*, 1939, No. 114, June 30, pp. 125-152). The author describes the investigation by a Tasmanian mining company of the relative merits of conventional drill-steel and Ingersoll-Rand detachable bits, the results of which indicated that the latter were more economical under the conditions prevailing at these mines. He describes in detail the process which was developed for the forging and heat treatment of the detachable bits.

**The Use of the Electric Industrial Heat-Treatment Furnace in Australia.** D. G. Poyitt. (*Australasian Engineer*, 1939, vol. 39, Aug. 7, pp. 18-19). The author describes and discusses the application, type, rating, temperature and control of electric heat-treatment furnaces in the eastern states of Australia, and shows that such furnaces are being extensively used for the heat treatment of carbon steels, high-speed tool steels and non-ferrous alloys, as well as for vitreous enamelling.

**New Plant for Rockford Heat-Treating Firm.** L. R. Foote. (*Heat Treating and Forging*, 1939, vol. 25, Sept., pp. 455-457). An illustrated description is given of the furnaces and quenching equipment for the heat treatment of tools recently installed at the new premises of a company at Rockford, Illinois.

**Electric Furnaces for Bright Annealing.** (*Engineering*, 1939, vol. 148, Oct. 20, pp. 440-441). An illustrated description is given of the electrically heated, continuous, roller-hearth furnace at the works of Arthur Lee and Sons, Ltd., which is used for the bright-

annealing of cold-rolled strip. The internal width is 2 ft. and the overall length 114 ft. It is suitable for operation at up to 1000° C., and its normal output is 15 cwt. per hr. A protective atmosphere of hydrogen and nitrogen obtained by cracking ammonia is used.

**Annealing of Low Carbon, Rimmed, Aluminium-Killed and Silicon-Killed Steels.** W. P. Wallace and R. L. Rickett. (American Society for Metals, Oct., 1939, Preprint No. 15). The authors examined the effects of the time and temperature of annealing and of the degree of previous cold-reduction on the structure and hardness of three types of steel, one silicon-killed, one aluminium-killed, and one rimming steel, all containing carbon 0.15% max. The temperature range covered was 900–1350° F. and the holding times at each temperature were 15 min., 2 hr. and 16 hr. The results are presented in numerous graphs and a three-dimensional diagram. The only consistent difference in the behaviour of aluminium- and silicon-killed steels which the authors observed was that when annealed at 1100° F. the former recrystallised and softened after smaller amounts of cold-reduction to a greater degree than did the latter.

**Hardness Characteristics of some Medium Carbon S.A.E. Steels.** P. Klain and C. H. Lorig. (American Society for Metals, Oct., 1939, Preprint No. 22). The authors study the hardening characteristics of sixteen S.A.E. plain carbon, and alloyed medium carbon steels as revealed by tests on quenched, and on quenched and tempered specimens  $\frac{1}{8}$ , 1, 2 and 3 in. in dia.

**Heating and Liquid Quenching Massive Sections.** J. A. Duma. (Heat Treating and Forging, 1939, vol. 25, Sept., pp. 447–451). The author discusses the laws governing the rate of heat transfer and applies them to calculations respecting the correct heating rates, holding times and cooling rates for round steel bars of various sizes when heat-treating.

**Time Quenching.** J. L. Burns and V. Brown. (American Society for Metals, Oct., 1939, Preprint No. 17). The authors studied the effects produced by different quenching procedures on the hardness and structure of specimens of S.A.E. 1040 and 1060 steels. The three methods of quenching adopted were: (a) Simple quenching in water for a given time, and completion of the cooling in air; (b) double quenching, *i.e.*, quenching in water for a given time and completion of the cooling in oil; and (c) interrupted quenching by quenching in water for a given time, exposing in the air for a given time and final quenching in water. They present the results by means of curves and macrographs.

**A Test Method for the Evaluation of Aqueous Quenching Media for Steel Hardening.** F. W. Trembour and H. Scott. (American Society for Metals, Oct., 1939, Preprint No. 18). The authors describe a method of testing the relative merits of aqueous quenching solutions; this method is based on the quantitative measurement of the area of the soft spots occurring in the quenched steel,

the formation of which was purposely accelerated by raising the temperature of the bath. They found that the optimum concentrations of aqueous solutions of sodium chloride and sodium hydroxide were 9% and 3% respectively, and that, if almost saturated solutions were used, these had a definitely harmful effect on the specimens.

**The Tempering of High-Speed Steel.** M. Cohen and P. H. Koh. (American Society for Metals, Oct., 1939, Preprint No. 1). The authors investigated the mechanism of the tempering and secondary hardening of high-speed steel (tungsten 18%, chromium 4%, vanadium 1%) by means of X-ray, hardness, specific volume, electrical resistance, dilatometric and magnetic measurements on hardened specimens tempered at various temperatures for times ranging from one minute to several hundred hours. They present a detailed picture of the tempering process. They attribute secondary hardening to the precipitation of complex carbides from the residual austenite and the transformation of this austenite into martensite. The austenite transforms during the cooling from the tempering temperature, and the amount which is transformed depends principally upon the time and temperature of the tempering treatment. They also report on the effects of other variables on the austenite transformation.

**The Industrial Application of Austempering.** E. E. Legge. (Metals and Alloys, 1939, vol. 10, Aug., pp. 228-242). After explaining briefly the theory of austempering (*see* Journ. I. and S.I., 1939, No. II., pp. 94 A and 341 A), the author describes the plant and technique employed by the American Steel and Wire Co., which applies this process on an industrial scale. He also gives the tensile strength and hardness values of a variety of austempered products, points out the limitations of the process and gives particulars of the gases consumed for fuel and for preparing the protective atmosphere for the hardening furnace. He finds that, working on the scale described, the cost of austempering is approximately the same as that of the conventional heat treatment and tempering process.



## WELDING AND CUTTING

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**Fundamental Nature of Welding.** D. E. Babcock. (Welding Journal, 1939, vol. 18, Aug., pp. 477-479). The author discusses the effects of the heating velocity and melting and diffusion of the iron carbide on the structure of welds made by the spot, flash and resistance processes.

**Recent Electric Welders.** (Engineering, 1939, vol. 148, Oct 6, pp. 382-384). Brief descriptions with illustrations are presented of some of the latest types of electric-welding machines now offered by the leading English and American manufacturers. These include motor-driven, petrol-engine-driven and Diesel-engine-driven generators, triple-frequency transformer sets and automatic continuous-feed welding machines.

**When and How to Preheat.** C. C. Notebaert. (Welding Journal, 1939, vol. 18, Sept., pp. 523-527). The author reviews the principles applied and the technique involved in the preheating of certain metals before welding and in the subsequent annealing.

**Burning during Welding of Mild Steel Sheet.** T. Swinden and H. Sutton. (Oxy-Acetylene Convention, London, Sept., 1939, Paper No. 4). During the gas welding of certain mild-steel sheets manufactured to British Standard Specification 353 it has been found that the backs of the welds had a frothy or burned appearance on the underside, particularly when penetration was complete. In this paper the authors report on their investigation of the causes of this. A microscopical examination of such welds revealed porosity in the form of blowholes, as well as oxide inclusions. The samples they examined showed varying degrees of susceptibility to burning, and these were subjected to full chemical analysis, including oxygen, nitrogen and hydrogen determinations. From the results obtained the authors are of the opinion that the tendency to burning is not associated with the content of any of these three gases, but it appears to be greatly influenced by the content of residual elements in the steel, the presence of which increased the tendency. The presence of silicon, however, decreased the tendency.

**Notes on the Welding of 18/8 Stainless Steel and its Derivatives.** R. Vaillant. (Corrosion Conference, Paris, 19-24 Nov., 1938 : Chimie et Industrie, 1939, vol. 41, April Special Number, pp. 231-233). The author considers the factors affecting the choice of the best welding technique to employ for stainless steels and methods of determining the susceptibility of these steels to intergranular corrosion.

**Welding Copper Steels.** W. Spraragen and G. E. Claussen. (Welding Journal, 1939, vol. 18, Sept., pp. 289-S-301-S). The authors review the literature to July, 1937, on the welding of copper-bearing steels and include a bibliography with 84 references.

**The Effects of Carbon on the Welding of Plain Carbon Steels.** W. Spraragen and G. E. Claussen. (Welding Journal, 1939, vol. 18, Aug., pp. 272-S-287-S). The authors present a review of the literature to July, 1937, on the effects of carbon on the welding of plain carbon steels. A bibliography with 106 references is appended.

**The Application of Oxy-Acetylene Welding and Cutting to the Manufacture and Repair of Locomotives.** A. H. C. Page and G. Foster. (Oxy-Acetylene Convention, London, Sept., 1939, Paper No. 1). The authors describe the equipment and technique employed by the London Midland and Scottish Railway in the oxy-acetylene welding department of their locomotive shops for the construction and maintenance of their locomotives.

**Trackwork Welding by the Oxy-Acetylene Process on the L.M.S. Railway.** N. W. Swinnerton. (Oxy-Acetylene Convention, London, Sept., 1939, Paper No. 3). The author introduces his subject by reference to the growth of oxy-acetylene welding as applied to trackwork on the London Midland and Scottish Railway and to the fields of application of the process. He deals in detail with the application of oxy-acetylene welding to the resurfacing of switches and crossings and their repair, and also to the bonding and welding of other components connected with the installation and maintenance of electric trackwork.

**Theoretical and Practical Considerations of Bronzewelded Cast-Iron Supply Mains.** F. W. Harper. (Oxy-Acetylene Convention, London, Sept., 1939, Paper No. 5). The author describes the materials used for the bronze-welding of joints in cast-iron gas mains. He also discusses some laboratory tests and field data obtained with regard to gas mains joined by this process at Sydney, Australia. He includes particulars of the time required and gases consumed in making the joints, and stresses that great care must be taken to avoid "humps" and "sags" when burying long lengths of bronze-welded pipes.

**Bronze Welding or Brazing of Iron and Steel by the Oxy-Acetylene Process.** (International Acetylene Association, 1939, Oxy-Acetylene Committee Publication Section VII.). A detailed account is given of the theory and practice of the process of making joints and building-up worn parts by brazing.

**Hard-Surfacing of Steel by Welding.** E. D. Lacy. (Metal Treatment, 1939, vol. 5, Autumn Issue, pp. 136-138, 142). The author describes the technique of depositing coatings of hard wear-resisting steel by electric welding on to tools and implements such as excavator and dredger buckets, crusher jaws, agricultural implements, impellers and pulveriser hammers.

**Flame Gouging : An Economical Method of Grooving Steel.** H. E. Rockefeller. (Iron Age, 1939, vol. 144, Sept. 14, pp. 53-57 ; Sept. 21, pp. 50-52). The author describes a new application of the oxy-acetylene blow-pipe. The principle of this process is based on the fact that if a nozzle designed to deliver a relatively large jet of oxygen at low velocity is properly manipulated, a smooth uniform groove can be cut or gouged out of the surface of the steel. By using different nozzles and manipulations the width and depth of the groove can be varied at the will of the operator. In the first part of this article the author describes and illustrates some examples of the use of this process. These include the preparation of surfaces for welding, the removal of weld metal, plant maintenance, plate-edge preparation and miscellaneous uses. In the second part he describes the equipment and technique employed and gives particulars of the types of steel which can be cut in this way.

**Notched-Bar Test Behaviour of Some Welding Steels.** C. E. Jackson and E. A. Rominski. (Welding Journal, 1939, vol. 18, Sept., pp. 312-S-317-S). The authors report on an investigation of the notched-bar impact values of welded joints in twenty-three plain and alloy steels. Temperature gradients in the heat-affected zone were measured by means of a series of thermocouples, and Charpy impact tests were made on specimens with the notches cut at different positions in and adjacent to the weld metal. The effects of preheating and of subsequent annealing were also studied.

**Welding Codes and Specifications.** (International Acetylene Association, 1939, Oxy-Acetylene Committee Publications, Section IV.). In this publication there are presented a number of welding codes and specifications agreed upon by various American societies for the fusion-welding of boilers, unfired pressure vessels, pressure piping, tanks, bridges and machinery construction.

**Specifications for Welded Constructions.** (Revue de la Soudure Autogène, 1939, vol. 31, Aug., pp. 750-762). A summarised version of some of the specifications and acceptance tests for electric and oxy-acetylene welded articles issued by l'Institut de Soudure Autogène is presented. These specifications include steel containers for compressed, liquefied or dissolved gases, petrol storage tanks, low-pressure and high-pressure vessels, and steel pylons.

## CLEANING AND PICKLING OF METALS

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**Cleaning Polished Steel.** J. S. Brady. (Steel, 1939, vol. 105, Oct. 9, pp. 62-63, 71). The author gives brief particulars of an electrolytic method of cleaning articles made of cold-rolled polished steel sheet which after some mechanical operations have grease, abrasive particles and metal particles left on them. The process described by the author is said to remove easily all three of these, leaving an excellent surface ready for the plating process.

**The Chemistry of Pickling.** G. Batta and E. Leclerc. (Corrosion Conference, Paris, 19-24 Nov., 1938 : Chimie et Industrie, 1939, vol. 41, April Special Number, pp. 292-296). The authors study the chemical actions which occur in the pickling process, dealing in turn with the metal to be cleaned, the material to be removed and the reaction products. They also discuss the action of inhibitors.

**The Layout of a Modern Continuous Strip-Pickling Plant.** (Sheet Metal Industries, 1939, vol. 13, Aug., pp. 994-996). An illustrated description is presented of the continuous pickling plant recently completed at the Cardiff works of Guest, Keen & Nettlefolds, Ltd.

**Pickle-Tank Control.** (Steel, 1939, vol. 105, Aug. 21, pp. 45-46). A description is given of the improvements carried out on an American continuous pickling plant. The acid baths are heated by steam jets discharging into the acid; control of the temperature was originally effected by a combined temperature recorder and controller operating a diaphragm form of valve. This form of control has been replaced by potentiometer type instruments which operate positive motor-driven steam valves. With these instruments it is possible to maintain the tank temperatures within 2° or 3° F. of the predetermined temperature.



## COATING OF METALS

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**Review of Electro-Plating Methods in France.** M. Ballay. (Proceedings of the American Electro-Platers' Society, Twenty-seventh Annual Convention, June 19-22, 1939, pp. 30-36). The author sets forth the features especially characteristic of the French plating industry, laying emphasis on such points as distinguish it from similar industries in other countries, particularly in America.

**Recent Developments in British Plating Practice.** C. Francis-Carter. (Proceedings of the American Electro-Platers' Society, Twenty-seventh Annual Convention, June 19-22, 1939, pp. 9-16). The author surveys some of the developments to plant and processes which have occurred in England in large-scale plating practice since the first International Conference was held in March, 1937.

**Current Density Range Characteristics—Their Determination and Application.** R. O. Hull. (Proceedings of the American Electro-Platers' Society, Twenty-seventh Annual Convention, June 19-22, 1939, pp. 52-59). The author describes a simple and accurate plating test for the determination of current density ranges and characteristics of deposits which can also be used to determine the effects of addition agents or of impurities upon deposits.

**The Measurement of  $pH$  in Alkaline Cyanide Plating Baths.** M. R. Thompson. (Proceedings of the American Electro-Platers' Society, Twenty-seventh Annual Convention, June 19-22, 1939, pp. 200-203). The author describes methods of measuring the  $pH$  value of alkaline plating baths such as the cyanide solutions of copper, brass, zinc and cadmium, and points out why the values obtained may differ from the true  $pH$  value.

**Some Simple Methods of Testing Protective Coatings.** R. I. Johnson. (Sheet Metal Industries, 1939, vol. 13, Sept., pp. 1127-1129; Oct., pp. 1247-1248). The author describes a number of simple and indirect methods of revealing defects in protective coatings on steel sheets. These methods fall into four well-defined groups, as follows: (a) The application of a solution which reacts with the base material to produce a coloured reaction product but has no effect on the protective coating; (b) the application of a coloured solution or a fluorescent material the penetration of which into the cracks or pores in the coating may readily be observed; (c) treatment by one solution which penetrates into defects in the coating, followed by treatment with a second solution which will react with the first to give a coloured reaction product; and (d) where an insulating coating is used on a conducting base, electric methods may be used which depend on the conduction of electricity through a conducting medium which will penetrate the pores or cracks in the insulating coating.

**A Study of the Thickness and Consistency of Protective Coatings.** (Corrosion Conference, Paris, 19-24 Nov., 1938 : *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 415-422). This is a report issued by Corrosion Committee No. 4 of the Dutch Central Institute for the Study of Materials, and it gives the results of numerous exposure tests undertaken to determine the relative values of different paints for the protection of steel against corrosion in the atmosphere of the Dutch East Indies.

**Dropping Tests for Measuring the Thickness of Zinc and Cadmium Coatings on Steel.** A. Brenner. (Proceedings of the American Electro-Platers' Society, Twentieth-seventh Annual Convention, June 19-22, 1939, pp. 204-208). The author studies the dropping test devised by S. G. Clarke and modified by R. O. Hull and P. W. C. Strausser by which the thickness of metallic coatings can be determined. In this test an ammonium nitrate or a chromic acid reagent is allowed to drop at a predetermined constant rate upon the specimen, and the thickness of the coating is calculated from the time taken for the drops to penetrate the coating and expose the base metal.

**The Chemical Determination of Local Thickness of Electrodeposited Metallic Coatings by the B.N.F. Jet-Test.** S. G. Clarke. (Proceedings of the American Electro-Platers' Society, Twenty-seventh Annual Convention, June 19-22, 1939, pp. 24-30). The author gives an account of the B.N.F. jet test for determining the thickness of metal coatings. The test has been so named because it was developed with the aid of funds contributed by the British Non-Ferrous Metals Research Association. In this test an apparatus is used which delivers a jet of a suitable reagent at a constant velocity on to the desired spot on the surface of the plated article. The liquid "bores" through the coating at a constant rate at the temperature of testing. The thickness is obtained by a simple proportion from the time required for perforation. With composite coatings the time for perforation of each layer is determined, and the thickness of each is worked out separately.

**An Electrical Method for End-Point Determinations in the Jet Test for Thickness of Metal Plating.** A. J. Lindsey and L. E. Terrett. (Journal of the Society of Chemical Industry, 1939, vol. 58, Sept., pp. 288-290). In the original jet test for determining the thickness of metallic coatings a stream of corrosive liquid is made to impinge under controlled conditions upon the surface of the specimen (*see* preceding abstract), and some difficulty is experienced in observing the disappearance of the plating. In this paper the authors describe an electrical method of indicating the instant at which complete removal occurs. The necessary apparatus and the technique are described and the results of experiments with plated materials are given.

**The Standardisation of the Quality of Electrolytic Coatings of Nickel and of Chromium.** M. Ballay. (Corrosion Conference, Paris,

19-24 Nov., 1938 : *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 278-283). The author considers methods of determining the thickness, continuity and adherence of nickel and chromium coatings on steel and suggests standard specifications to define these properties.

**Porosity Tests on Electro-Plated Coatings.** P. W. C. Strausser. (Proceedings of the American Electro-Platers' Society, Twenty-seventh Annual Convention, June 19-22, 1939, pp. 194-200). The author describes the ferroxyl porosity test, the hot-water test, the iodine test and the salt-spray test as used by the National Bureau of Standards for determining the porosity of electrodeposited coatings on steel without resorting to long-time exposure tests. He found that for nickel and chromium coatings on iron or steel, the modified ferroxyl test of porosity yielded results consistent with the thickness of coating and the behaviour on outdoor exposure. The hot-water test was less sensitive and the iodine test was unsatisfactory. The salt-spray test on thick coatings was more severe than the modified ferroxyl test and gave less consistent results.

**The Application of X-Ray Diffraction Analysis to Electro-Plating Problems.** H. R. Isenburger. (Proceedings of the American Electro-Platers' Society, Twenty-seventh Annual Convention, June 19-22, 1939, pp. 77-83). The author describes a modern X-ray diffraction apparatus and discusses, with numerous examples and illustrations, the results obtained with it when examining electrodeposited coatings.

**Notes on the Adhesion of Electrodeposited Metals to Steel.** A. W. Hothersall. (Proceedings of the American Electro-Platers' Society, Twenty-seventh Annual Convention, June 19-22, 1939, pp. 1-7). The author discusses the reasons for the excellent adhesion of nickel coatings electrodeposited on steel, stating that the bond is not due to mechanical interlocking, but that the coating and the base are held together by atomic forces. In support of this statement he shows that the microstructure of copper, deposited over a thin coating of nickel, will be similar to that of annealed iron. He gives the results of tests which show that weakness of the surface of steel, either intrinsic or produced by hydrogen, can reduce adhesion to a very low value. He also describes the anodic etching of steel in sulphuric acid.

**The Adhesion of Electro Deposits.** F. C. Mesle. (Proceedings of the American Electro-Platers' Society, Twenty-seventh Annual Convention, June 19-22, 1939, pp. 152-168). After describing his method of determining the adhesion of electrodeposited metals, the author presents data obtained by this method using specimens coated with nickel, copper, Britannia metal, nickel-silver, silver and tin.

**A Study of Electrolyte Films.** A. K. Graham, S. Heiman and H. J. Read. (Proceedings of the American Electro-Platers' Society, Twenty-seventh Annual Convention, June 19-22, 1939, pp. 95-105).

In the solution of a metal at an anode or its deposition at a cathode, the composition of the electrolyte film determines the nature of the anode attack or the character of the deposit. In the electroplating process the commonly recognised variables of importance only exert their influence by the manner in which they affect the electrolyte film. In this paper the authors give an account of their study of the composition of electrolyte films. They first describe the method they developed for sampling the films, and then apply the method to a study of the cathode films from several nickel electrolytes. They draw the following general conclusions from the observations made: (1) The "decrease in chloride" appears to be the most profound change taking place in the cathode films of the nickel electrolytes, and may be associated with burning. (2) The nickel concentrations of the cathode films also decrease, but to a less extent than the chloride. The decrease in the hydrogen-ion concentration in the cathode films is large, but expressed in pH units the changes are small and well within the limits ordinarily applied in the control of the plating baths. (3) While the changes reported are compared in terms of the average current density, the effect of high local current densities can be predicted from the data.

**Complex Cations as the Important Influence in Plating Baths.** F. C. Mathers. (Proceedings of the American Electro-Platers' Society, Twenty-seventh Annual Convention, June 19-22, 1939, pp. 134-139). The author considers the possible effects of the exceptionally complex nature of solutions upon the character of electrodeposits. In that part of his paper dealing with experiments, he shows that halogens are deposited with, or are present in various metals electrodeposited from halide solutions. His final conclusion regarding halogens in plating baths is that each metal is a law unto itself, as no regularity was noted between the quantity of halogen in the solution and the quantity in the deposit.

**Chromium Plating Dies and Gauges.** D. A. Cotton. (Proceedings of the American Electro-Platers' Society, Twenty-seventh Annual Convention, June 19-22, 1939, pp. 61-67). The author describes the development of the application of chromium-plating to dies for moulding synthetic resins and to the building-up of worn inspection gauges and other tools at a department of the General Motors Corporation.

**Electrodeposition of Black Molybdenum Finishes.** R. A. Hoffman and R. O. Hull. (Proceedings of the American Electro-Platers' Society, Twenty-seventh Annual Convention, June 19-22, 1939, pp. 45-49). The authors describe the process of producing a highly lustrous, deep-black deposit using a solution containing essentially ammonium molybdate, nickel sulphate and boric acid. From a plating standpoint this process has two quite unusual features. The first is the high rate of deposition even at low current densities, for the deposit can be produced twenty-one times as rapidly as



nickel under identical conditions. The second is the throwing power of 81–89% as measured by the Haring cell; this is higher than that of any other known plating system.

**Hot Coating Steel Wire with Aluminium.** R. J. Snelling and E. T. Richards. (Wire and Wire Products, 1939, vol. 14, Aug., pp. 425, 442–443, 448). The authors survey some of the methods of applying a coating of aluminium to steel wire.

**A Study of Silver Plating for Industrial Applications.** A. J. Dornblatt, C. S. Lowe and A. C. Simon. (Proceedings of the American Electro-Platers' Society, Twenty-seventh Annual Convention, June 19–22, 1939, pp. 214–223). The authors present the results of investigations relating to industrial applications of silver plating. Methods of testing porosity are discussed and compared. They report on the effects of (a) the surface quality of the base metal, (b) undercoats of copper and nickel, and (c) pressing operations, upon the porosity of the coating. In conclusion they discuss how these effects influence the development of silver-lined containers.

**New Cladding Method Holds Important Possibilities.** (Steel, 1939, vol. 105, Oct. 2, pp. 42–43, 63–64). A new development of resistance welding is described by which sheets of stainless steel can be attached to carbon steel, the entire area being welded. The process was developed to protect pressure-vessels used in chemical processes from corrosion. By this process layers up to  $\frac{1}{8}$  in. in thickness can be welded on to steel from  $\frac{1}{2}$  in. to 3 in. thick. The electrodes used consist of two large copper alloy wheels capable of carrying nearly 30,000 amp. and of exerting a high mechanical pressure on the plate. These wheels traverse the surface, leaving a welded strip about  $\frac{5}{8}$  in. wide at each pass. In order to prevent the migration of carbon from the base metal to the stainless-steel layer, it has been found possible to weld between them a sheet of pure nickel 0.01 in. thick. For technical reasons it has been found necessary to apply the stainless steel in two layers. The welding of these two layers and the nickel sheet to the steel is done in one operation. The process is called "Croloy" bonding.

**The Protection of Ferrous Metals Against Corrosion by Phosphatising before Painting.** J. Bignon. (Corrosion Conference, Paris, 19–24 Nov., 1938 : Chimie et Industrie, 1939, vol. 41, April Special Number, pp. 427–430). The author discusses the results of a series of tests on specimens of steel plate which demonstrated the beneficial effect of phosphatising the surface prior to painting it.

**The Evolution of the Technique of Phosphatising in the World.** J. Bary. (Corrosion Conference, Paris, 19–24 Nov., 1938 : Chimie et Industrie, 1939, vol. 41, April Special Number, pp. 431–432). The author gives a brief account of the progress made in the technique of phosphatising in the industrial countries of the world.

**Comparison of Methods of Zinc Coating.** (Metal Treatment, 1939, vol. 5, Autumn Issue, pp. 131–136). The hot-galvanising,

zinc-powder, zinc-plating and metal-spray processes of applying a zinc coating to iron and steel are reviewed and compared, and it is pointed out that the metal-spray method of application demands wider recognition than it receives at present, for the same equipment can be used for applying other metals than zinc, and for spraying a method on to a structure made of more than one metal.

**Zinc-Coating Processes and Surface Protection of Zinc Layers and Zinc Alloys.** H. Bärmann. (Metallwirtschaft, 1939, vol. 18, Aug. 25, pp. 743-746.) The author discusses the progress made in the field of electrolytic zinc-plating, protective coatings on zinc coatings and zinc alloys produced by treatment with an acid chromate solution, and the protection of zinc coatings and zinc alloys by the application of electrodeposited coatings of chromium. Protection by chromate treatment appears to be satisfactory, provided that the conditions of exposure of the treated articles do not allow the protective coating to be washed away; corrosion tests on zinc die castings under static immersion conditions and on zinc-coated iron sheets in the spray apparatus showed that the chromate treatment gave definite protection, but in tests made in running water the difference between chromate-treated and untreated articles disappeared, because the chromate film was slowly washed away. The protection of zinc coatings or zinc alloys by chromium-plating appears to be extremely difficult; the very exact conditions required during plating must be precisely maintained, an intermediate layer (say, copper) must be applied, and even then the author, referring to tests in running water, only speaks of protection lasting several weeks. (See next abstract.)

**Electrolytic Zinc or Cadmium-Plating?** E. Zettler. (Metallwirtschaft, 1939, vol. 18, Aug. 25, pp. 746-748). The author first discusses the relative merits of electrodeposited coatings of zinc and cadmium as protections against corrosion; he states that electroplated zinc is at least the equal of electroplated cadmium in this respect. As a result of recent advances in bright electroplating, bright zinc coatings are in no way inferior to bright cadmium coatings, in regard to either rust protection, surface reaction or speed of plating. Under certain conditions these bright coatings lose their lustre, and several ways of protecting them are available; the author says that the best method is to chromium-plate the zinc coating after applying a thin intermediate layer of copper, but adds that opinions differ as to whether this chromium-plating decreases the protective power of the zinc or not (see preceding abstract). Other advantages of zinc over cadmium are that it is harder, its melting point is higher and it is cheaper.

**Improved Galvanizing.** (Steel, 1939, vol. 105, July 24, pp. 52-55). An illustrated description is given of the lay out and of some of the appliances which increase the efficiency of the galvanising department of the Inland Steel Co., Indiana Harbor.

**American Hot-Dip Galvanising Practice.** W. G. Imhoff. (Blast Furnace and Steel Plant, 1939, vol. 27, Feb., pp. 180-185, 204; Mar., pp. 262-268; Apr., pp. 362-365, 411; July, pp. 686-689; Sept., pp. 952-955). Continuation of a series of articles. (See Journal I. and S.I., 1939, No. I, p. 291 A). In Part X. of this series the author describes in detail the process of galvanising American domestic boilers, paying particular attention to the causes of defects. By quoting examples from practical experience, he explains the procedure to be followed in order to produce a well-finished boiler. Parts XI. and XII. the author devotes to discussing the characteristics of malleable-iron castings, the causes of the embrittlement of such castings when galvanised by the hot-dip method and the galvanising equipment and process used. He refers to the high percentage of dross formed when galvanising malleable iron; the main cause of this is that molten zinc reacts with iron more readily than with steel. In Part XIII. the author discusses the galvanising of refrigerator parts, electric heating elements for immersion heaters and fittings for dairy machinery. Part XIV. is devoted to descriptions of some galvanising shops where a great variety of work is undertaken; some particulars of the production and costs at these works are also given.

**New Facilities in Hot-Dip Galvanizing Department Are Installed without Interrupting Production.** A. L. Jackson. (Steel, 1939, vol. 105, Aug. 28, pp. 58-60). The author describes the new galvanising plant recently installed by the International Derrick and Equipment Co. of Columbus, Ohio, and the plan followed during its erection, which enabled continuous production to be maintained.

**Protection against Corrosion by Electrolytic Tin and Lead Coating.** M. Schlötter. (Corrosion Conference, Paris, 19-24 Nov., 1938: Chimie et Industrie, 1939, vol. 41, April Special Number, p. 285). The author gives a brief description of electrolytic methods of applying lead and tin coatings to steel.

**Metal Spraying with Rustless Chromium Steel.** P. Leder. (Steel, 1939, vol. 105, July 31, pp. 38-39). The author describes how worn parts such as cast-iron plungers and steel piston rods can be reconditioned by the application of high-carbon, chromium steel with a metal-spraying gun.

**The Protection of Steel Tubes by an Asbestos-Cement Coating.** A. Rocca. (Corrosion Conference, Paris, 19-24 Nov., 1938: Chimie et Industrie, 1939, vol. 41, April Special Number, pp. 477-481). The author describes the machinery used for coating steel tubes with asbestos-cement and discusses the results achieved by this process in the light of several years' experience in Italy.

**The Protection of Steel Against Atmospheric Corrosion by Means of Paints.** J. C. Hudson. (Corrosion Conference, Paris, 19-24 Nov., 1938: Chimie et Industrie, 1939, vol. 41, April Special Number, pp. 407-414). See Journ. I. and S.I., 1939, No. I., p. 39 A.

**The Study of Coatings for Protection Against Corrosion by l'Office National des Recherches et Inventions.** A. Vila. (Corrosion Conference, Paris, 19-24 Nov., 1938 : *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 433-442). The author reviews the research done on protective coatings since 1933 in France under the direction of l'Office National des Recherches et Inventions. He describes an apparatus for making rapid tests on paints which simulates the destructive effects of industrial atmospheres and discusses the preparation of metal surfaces before painting, and the action of light on paints. In conclusion he describes the respirators used by paint-spraying operators.



## PROPERTIES AND TESTS

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**Yield Point Phenomena.** (Metallurgist, 1939, vol. 12, Oct., pp. 71-73). Kuroda's theory in explanation of the appearance of Lüders lines and of the yield-point extension in the stress-strain curve for soft steel is discussed. In this theory Kuroda postulates a honeycomb structure of envelopes of carbide and impurities surrounding ferrite crystals in an attempt to explain the phenomena and their dependence on the effect of cold-work. (*See* "On the Origin of the Yield-Point Phenomena of Soft Steel," Journ. I. and S.I., 1939, No. I., p. 229 A).

**Influence of the Resiliency of the Test Machine and of the Loading Speed upon the Determination of the Yield Point for Mild Steel.** G. Welter and S. Gockowski. (Metallurgia, 1939, vol. 20, Aug., pp. 143-148). The authors describe further investigations of the effect of the elastic behaviour of the testing machine upon the determination of the yield point of mild steel (*see* Journ. I. and S.I., 1938, No. II., p. 33 A). They explain how tensile testing machines of 5, 20 and 50 tons capacity can be damped by fitting a helical spring in the case of the small machines and a pressure chamber in the case of the powerful hydraulic machines, and compare the stress-strain diagrams obtained with the rigid and the damped machines from the same kinds of steel. The effect of the rate of loading upon the shape of the stress-strain curve is also discussed.

**Tensile Elastic Properties of 18 : 8 Chromium-Nickel Steel as Affected by Plastic Deformation.** D. J. McAdam, jun., and R. W. Mebs. (National Advisory Committee for Aeronautics, 1939, Report No. 670). The authors discuss the relationship between stress and strain, and between stress and permanent set in 18/8 chromium-nickel steel and how this is affected by previous plastic deformation. They also consider hysteresis and creep and their effects on the stress-strain and stress-set curves, as well as the influence of the duration of the period of rest after cold-work and the influence of plastic deformation on the proof stress, on the modulus of elasticity at zero stress, and on the curvature of the stress-strain line.

**The Stress-Strain Characteristics of the Torsion Impact Test.** O. V. Greene and R. D. Stout. (American Society for Metals, Oct., 1939, Preprint No. 5). The authors state that the torsion-impact value of a specimen is a measure of the toughness of the specimen in foot-pounds, but it does not indicate the relative magnitude of the strength and plasticity characteristics of the steel; they therefore investigated the relative importance of these factors and

measured their actual values using specimens of 1.10% carbon tool steel subjected to different forms of heat treatment. They reproduce a number of stress-strain-torsion curves for this steel and describe a method of calculating the stress-strain data from the results of torsional impact tests.

**Impact Properties of Some Low-Alloy Nickel Steels at Temperatures down to -200 Degrees Fahr.** T. N. Armstrong and A. P. Gagnebin. (American Society for Metals, Oct., 1939, Preprint No. 9). The authors present and discuss the results of Charpy impact tests at temperatures from -75° F. to -200° F. on specimens of nickel and nickel-molybdenum steels. From the data obtained it is seen that the following steels possess good impact-resistance properties at low temperatures : (1) Properly deoxidised, normalised and tempered cast steel containing carbon 0.15% max., nickel 3.5-4%, and cast steels containing carbon 0.15% max., nickel 2.75% and molybdenum 0.30% ; (2) normalised and tempered wrought steels containing carbon 0.17% max., and nickel 2.75% min. ; the optimum nickel content in the plain nickel steel appears to be 3.5-4.0% ; and (3) normalised and tempered wrought steels low in carbon that have been deoxidised with aluminium and contain substantial quantities of nickel and molybdenum.

**The Theories of Cold-Working and Strengthening.** G. Masing. (Zeitschrift für Metallkunde, 1939, vol. 31, July, pp. 235-238). The author reviews the existing theories of the plastic deformation and slip which occur during the cold-working of metals and discusses methods of calculating the stresses required to cause plastic deformation to commence and to continue to a given point.

**Internal Stresses in Piston-Rods of a Large Diesel-Engine Ocean Liner.** G. Sachs. (Transactions of the American Society for Metals, 1939, vol. 27, Sept., pp. 821-836). The author describes an investigation of the causes of the failure of five of the twenty-four piston rods in the Diesel engines of an ocean liner. The rods were made of a heat-treated high-strength steel in which it was found that there were high residual stresses. The fatigue failures had started where these stresses were concentrated, and failure was accelerated by corrosion of the surface of the hole down the centre of the rod by the cooling agent used. The author also describes his method of determining the value of the residual stresses.

**The Physics of Metals. V. and VI.** P. Malaval and P. Bernard. (Mémorial de l'Artillerie Française, 1939, vol. 18, No. 69, pp. 3-12 ; No. 70, pp. 217-254). Continuation of a series of articles (see Journ. I. and S.I., 1939, No. II., p. 229 A). In Part V. the authors discuss the theory of the deformation of metals and describe a number of tests by which the movement occurring within a body as the result of the application of external forces can be studied. In Part VI. they study the deformation of single crystals and the relation between the crystalline structure of a metal and the slip when the metal is subjected to deformation.

**Methods of Preventing Shatter Cracks or Flakes in Carbon Steels.**

H. B. Wishart and A. N. Swanson. (Transactions of the American Society for Metals, 1939, vol. 27, Sept., pp. 784–796). The formation of internal cracks known as “shatter cracks” in the larger sections of high carbon steel may be prevented by two processes, namely, Brunorising and controlled or retarded cooling. In this paper the authors describe a third process allied to that of controlled cooling. The tests which the authors carried out fell into three groups, namely: (1) The controlled or retarded cooling of the steel, starting the retardation at different temperatures after the last hot-rolling operation. (2) The controlled or retarded cooling of the steel through different temperature ranges after the last hot-rolling operation. (3) The cooling of steel at a constant rate to any given temperature between 500° and 1400° F. after the last hot-rolling operation, holding at such temperature for various periods of time and finally cooling it in air from the holding temperature. The steels tested had been treated with hydrogen, which rendered them particularly susceptible to the formation of shatter cracks. The second group of tests showed that a retarded cooling applied after cooling to any temperature above about 400° F. prevents the formation of shatter cracks. The third group of tests showed that much time could be saved, as holding at 1000–1200° F. for only 1½ hr. was found to be effective in preventing the formation of cracks.

**The Prevention of Flakes by Holding Railroad Rails at Various Constant Temperatures.** R. E. Cramer and E. C. Bast. (American Society for Metals, Oct., 1939, Preprint No. 16). The authors describe some tests made in order to ascertain the length of time during which specimens of rails must be held at temperatures of 1100°, 900°, 700° and 500° F. so as to prevent the formation of flakes or shatter cracks. The steel contained 0.78% of carbon and about 0.90% of manganese. They also discuss the influence of hydrogen in the steel upon the formation of cracks and the mechanism and causes of flake formation. This work forms part of the investigation of fissures in rails (*see* Journ. I. and S.I., 1939, No. II., p. 346 A).

**The Fatigue Resistance of Steel as Affected by Acid Pickling.**

G. L. Kehl and C. M. Offenbauer. (American Society for Metals, Oct., 1939, Preprint No. 6). The authors describe an investigation of the effect of different pickling procedures on the fatigue strength of specimens of 0.54% carbon steel. The variations in the pickling included the use of different inhibitors, different periods of immersion, and changes of temperature, acid concentration and ferrous sulphate content.

**Stress Concentration Effects in Fatigue.** (Metal Treatment, 1939, vol. 5, Autumn Issue, pp. 108–114). An abridged account is presented of the results obtained in two recent investigations of the effects of the type of stress applied and of case-hardening on the properties of plain and of drilled steel specimens. These results

were previously reported in two papers, one entitled "The Effect of the Type of Stress on the Fatigue Strength of Drilled and of Notched Steel Test-Pieces" by F. Körber and M. Hempel, and the other entitled "The Effect of Case-Hardening on the Bend and Torsional Fatigue Strength of Plain and Drilled Specimens" by H. Wiegand and R. Scheinost. (*See Journ. I. and S.I.*, 1939, No. II., p. 33 A).

**Hardness Gradients in Tempered Steel Cylinders.** C. A. Rowe and R. A. Ragatz. (*Transactions of the American Society for Metals*, 1939, vol. 27, Sept., pp. 719-738). The authors describe an investigation of the hardness of 1-in.-dia. bars of nine plain carbon steels (carbon 0.17-1.20%) which were tempered at temperatures ranging from 400° to 1275° F. They present numerous curves showing the hardness gradients as well as micrographs illustrating the changes in structure. A study of the curves reveals that on tempering at progressively higher temperatures: (a) the martensitic case shows a considerable decline in hardness before any change in hardness is observable in the core; (b) the core commences to decrease in hardness before that of the martensitic case has decreased to that of the core of specimens "as quenched"; and (c) at the higher tempering temperatures the tempered martensitic case becomes softer than the tempered core.

**Hardenability Variations in Alloy Steels—Some Investigations with the End-Quench Test.** G. T. Williams. (*American Society for Metals*, Oct., 1939, Preprint No. 19). After describing the equipment and procedure for making "end-quench" hardness tests as developed by Jominy and Boegehold (a test in which only the end of the specimen is quenched under controlled conditions, *see Journ. I. and S.I.*, 1938, No. II., p. 378 A), the author reports the results of a large number of tests made in this way on nickel-chromium and nickel-chromium-molybdenum steels. He studies the hardness at different depths, the microstructure and the effects of preliminary heat treatment upon the hardness after quenching, and finds that alloy steels differ greatly in the holding time necessary to develop the maximum hardenability attainable below the temperature at which grain-growth commences. This difference in behaviour is not related to the standard chemical analysis or the grain size.

**A Hardenability Test for Shallow Hardening Steels.** W. E. Jominy. (*American Society for Metals*, Oct., 1939, Preprint No. 20). The author describes a modification of the "end-quench" hardness test (*see preceding abstract*) which is very suitable for shallow-hardening steels, and presents the results obtained by this method with specimens of high-, medium- and low-carbon steels. The feature of this test is that instead of having a flat end, the specimen has a tapered hole drilled in the end to be quenched, the effect of which is to lengthen the distance along the bar over which the variation in hardness can be measured.



**Hardenability Studies on Tool Steel.** A. J. Scheid, jun. (American Society for Metals, Oct., 1939, Preprint No. 29). The author discusses the hardenability characteristics of the principal types of tool steel, pointing out the influence of alloying elements such as tungsten, chromium and vanadium, and the effects of different forms of heat treatment.

**The Effect of Hardness and of Temperature on the Strength, Ductility and Toughness of a Heat Treated Carbon Steel.** S. W. Lyon. (American Society for Metals, Oct., 1939, Preprint No. 21). By making tensile, impact-tensile and impact-bend tests on un-notched specimens of steel of different hardness, the author studied the relation between these properties, and found that the steel loses strength, ductility and toughness quite markedly as the hardness increases from Rockwell C47 to C52. He also studied how these values are influenced by changes in the temperature at which the test is carried out in the range  $+70^{\circ}\text{F.}$  to  $-70^{\circ}\text{F.}$

**Hardness Conversion Relations for Hardened Steels.** H. Scott and T. H. Gray. (American Society for Metals, Oct., 1939, Preprint No. 28). The authors discuss the differences between the various methods of determining the hardness of steel and the causes of errors which occur in conversion from one scale to another. They present a hardness conversion chart in which the equivalent values of the diamond-pyramid, Rockwell, scleroscope, Monotron and Brinell hardness are compared by a series of parallel vertical scales, thus enabling differences of less than unity to be read.

**The Mechanism of Precipitation from Solid Solution. The Theory of Age-Hardening.** R. F. Mehl and L. K. Jetter. (American Society for Metals, Oct., 1939, Preprint No. 30). The authors discuss the changes in properties that accompany ageing in binary alloys. They describe the theory of nucleus formation in phase changes and consider the application of this theory to precipitation reactions in the solid state. From the available evidence they consider that the changes in properties observed may be explained on the basis of precipitation alone. A bibliography with 185 references is appended.

**Precipitation Hardening in the Heavy Alloys.** W. P. Sykes. (American Society for Metals, Oct., 1939, Preprint No. 37). The author presents and discusses the results of experiments made to discover how the precipitation-hardening of iron-tungsten and iron-molybdenum alloys is influenced by the following factors: (1) The atomic concentration of the alloying element; (2) the temperature of the precipitation treatment; (3) the degree of supersaturation of the solid solution; (4) the grain size of the solid solution; and (5) the addition of a third metal to a binary solid solution.

**Ageing in Iron and Steel.** R. L. Kenyon and R. S. Burns. (American Society for Metals, Oct., 1939, Preprint No. 40). The authors review the literature on the ageing of iron and steel, paying particular attention to the methods of testing and to the practical

aspects of the ageing of over-strained steels and of the ageing of drastically quenched steels. A bibliography with 382 references to the literature is appended.

**Bore Wear from the Viewpoint of Materials.** P. S. Lane. (S.A.E. Journal, 1939, vol. 45, Oct., pp. 413-420). The author describes laboratory methods of testing the wear of cylinders and piston rings, and presents the results of numerous hardness and loss-in-weight tests and microscopic examinations of grey cast iron, alloyed cast iron and nitrided steel and discusses their suitability for making piston rings.

**Magnetically Soft Materials.** T. D. Yensen. (Transactions of the American Society for Metals, 1939, vol. 27, Sept., pp. 797-819). The author discusses the effects of grain size, of grain orientation and of alloying elements on the magnetic properties of iron and iron-nickel alloys.

**A Simple Method of Thermal Analysis Permitting Quantitative Measurements of Specific and Latent Heats.** C. S. Smith. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1100: Metals Technology, 1939, vol. 6, Sept.). The author describes a fairly simple apparatus by which the specific and latent heats of metals can be determined. In this method the specimen with a thermocouple attached is placed in a refractory container of low thermal conductivity, and this is placed in an electric furnace the temperature of which is maintained a constant amount above or below that of the specimen. Under these conditions the time taken for the specimen to pass through a given range of temperature is proportional to the heat absorbed or evolved.

**On the Creep of Alloy Steels at High Temperatures.** H. Krainer. (Zeitschrift für Metallkunde, 1939, vol. 31, July, pp. 239-240). In this mathematical discussion the author considers some equations for calculating the creep rate of steels and he also presents a table showing creep data for fifteen alloy steels in various ranges of temperature.

**Some Things We Don't Know about the Creep of Metals.** H. W. Gillett. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1087: Metals Technology, 1939, vol. 6, Aug.). In this paper on what is not known about creep, the author points out that time and expense are the principal factors accounting for the lack of information and experimental data on creep, and because of this there is no lack of theoretical discussion of the subject. In discussing several examples of time-elongation curves, the author divides these into three phases: The initial phase in which the creep rate rises rapidly and then falls off to the beginning of the second phase, which represents a long period at a constant rate, and the final stage, which is usually extrapolated. He deals with the effects of grain size, alloying elements, stability at high temperatures, precipitation-hardening

and embrittlement on creep rates. He discusses both graphical and mathematical extrapolation and refers to the efforts which have been made to establish mathematical functions for strain-hardening, annealing, spheroidisation and precipitation-hardening effects and to combine them all into a formula that will express the future course of a creep curve for ten or twenty years, but considers that such efforts are of little value. In his opinion it is necessary to persevere with endeavours to obtain more data by painstaking research. A bibliography of ninety-four references to the literature on creep is appended.

**Creep Rate from Tests of Short Duration.** J. J. Kanter and E. A. Sticha. (American Society for Metals, Oct., 1939, Preprint No. 7). The authors describe a method of making short-time creep tests, and from data obtained by this method they estimated the long-time creep rates of specimens of cast chromium-molybdenum-silicon steel by extrapolation. They endeavour to show that under equal load conditions and with temperature as a variable a relationship exists between the short- and long-time creep rates.

**Investigation of the Structural Mechanism and Mechanical Behaviour of Metals at High Temperatures.** G. A. Homès. (Revue de Métallurgie, Mémoires, 1939, vol. 36, Aug., pp. 373-387). After reviewing the present state of knowledge of the processes of plastic deformation and cold-work, the author discusses the results obtained in investigating the following four aspects of the effect of high temperatures upon the properties of steel and copper: (a) The effects of heat and of time at temperature on the cold-worked metal; (b) the simultaneous effects of stress, heat and time; (c) the effect of holding at a high temperature for a long time; and (d) the deformation and rupture of crystals produced by heat.

**The Properties of Grey Cast Iron, with Special Reference to the New B.S. Specifications.** (Report of the Cast-Iron Sub-Committee of the Technical Committee of the Institute of British Foundrymen: Foundry Trade Journal, 1939, vol. 61, Sept. 21, pp. 199-201). In this report of the Technical Committee of the Institute of British Foundrymen many factors leading to the selection of the tests included in the original and revised British Standard Specifications for grey and high-duty cast irons are explained.

**A Note on the Effect of the Addition of Molybdenum, Tungsten and Titanium, together with Calcium Silicide, to Cast Iron.** J. E. Hurst. (Foundry Trade Journal, 1939, vol. 61, Oct. 19, pp. 265-266, 280). The author reports on a number of experiments undertaken as part of a study of various methods of making additions of certain of the higher-melting-point metals to cast iron. The additions were made by the use of an oxide of the alloying element in conjunction with a reducing agent. The reducing agent chosen was calcium silicide, and intimate mixtures of powdered calcium silicide and the metallic oxide were used in the experiments; a study was made of the yield of metallic alloy, and of any other



changes in the composition of the metal, particularly the silicon content. The tests were made by adding the mixture to refined pig irons melted in a crucible furnace. The author arrived at the following conclusions: (1) To ensure a yield of molybdenum in excess of 75% of added molybdenum metal it is advisable to grind the oxide sufficiently fine to pass a —50-mesh screen and to use an excess of calcium silicide. (2) The yield of molybdenum from its oxide when added as advised in (1) compared very favourably with the yield obtained by adding powdered ferro-molybdenum. (3) With 1% of molybdenum in the iron a tensile strength of approximately 30 tons per sq. in. and a modulus of rupture well over 50 tons per sq. in. were obtained. (4) Whilst the addition of calcium silicide alone reduced the sulphur content, the joint addition of this material and molybdenum oxide caused a much greater reduction of the sulphur content. (5) The yield of tungsten from mixtures of tungsten oxide and calcium silicide was not so good as was the case with molybdenum. (6) The yield of silicon in the molten metal, in spite of the larger amount of calcium silicide added, was less than in the case of the molybdenum-containing mixtures. (7) The elements molybdenum and tungsten did not exhibit the marked carbide-forming tendencies usually attributed to them. (8) In the case of additions of calcium silicide and titanium oxide the yield of titanium and that of silicon in the molten metal were exceptionally low; in spite of this the joint additions markedly reduced the combined-carbon content, but had very little effect on the sulphur content. (9) In all the experiments there was a slight reduction of the total-carbon content coincident with the addition of the powder, but there was no evidence that this was in any way proportional to the amount or nature of the addition.

**The Accelerating Effect of Certain Metallic Elements on Graphitization.** H. A. Schwarz, V. Fiordalis, J. L. Fisher, J. F. Shumar and M. J. Trinter. (American Society for Metals, Oct., 1939, Preprint No. 23). The authors examine the graphitisation-acceleration effect produced by copper and nickel on white cast iron, in order that these effects may be compared with the retardation effects of manganese, chromium, vanadium and molybdenum reported in a previous paper (*see* Journ. I. and S.I., 1937, No. I., p. 7 A). They come to the following conclusions: (1) The two elements copper and nickel produce approximately equal graphitisation-acceleration; (2) the effect of 1% of either element is about equal to that of 0.9% of silicon; (3) neither element materially alters the solubility of graphite in  $\gamma$ -iron; (4) nickel increases the number of very small nodules per unit of volume which are formed at 900° C., but has little effect on the number of the larger sizes; and (5) either element increases the rate of migration of carbon in  $\gamma$ -iron solution.

**Cast-Iron Crankshafts. II.** H. Kopp. (Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns, 1939, vol.



7, July, pp. 96–103). The author continues the discussion of the suitability of cast iron for making crankshafts, and describes the testing and physical properties of “Essling” crankshaft iron (*see* Journ. I. and S.I., 1938, No. I., p. 344 A). He shows that in order to exploit to the full the superior damping capacity of cast iron the design of a cast-iron crankshaft must differ from that of a forged-steel one, and he discusses these differences in detail.

**An Investigation of Wrought-Steel Railway-Car Wheels. Part I. Tests of Strength Properties of Wrought-Steel Car Wheels.** T. J. Dolan and R. L. Brown. (University of Illinois, 1939, Engineering Experiment Station, Bulletin No. 312). The authors describe an investigation the main purpose of which was to locate the most highly stressed portions of railway-wagon wheels under several types of loading, and to calculate (from strain measurements) the magnitude of the larger stresses occurring in the wheel under a given set of loading conditions. Tests were made on medium-carbon steel wheels and on silicon-manganese alloy-steel wheels. They describe the testing procedure in full detail and present and discuss the results obtained.

**Combination of Properties Is Strong Point of Malleable Castings.** C. T. Eakin. (Machine Design, 1939, vol. 11, Oct., pp. 37–39, 56–58). The author discusses the properties and applications of malleable-iron castings and compares them with those of cast and forged steel.

**The Effect of Titanium on the Macrostructure and Grain-Coarsening Temperature of Forging Steel.** G. F. Comstock. (American Society for Metals, Oct., 1939, Preprint No. 2). The author describes an investigation made with 17-lb. ingots to determine how the grain-coarsening temperature of plain carbon steel (about 0.37% of carbon) was affected by the presence of from 0.1 to 0.4% of residual titanium together with small additions of aluminium. He arrived at the following conclusions: (1) About 0.1% or more of titanium prevents the formation of coarse dendrites in small ingots of 0.35–0.40% carbon steel teemed at about 1595–1620° C., whilst similar amounts of aluminium or zirconium do not produce this effect. (2) With over 0.2% of titanium and the addition of 0.05–0.15% of aluminium the grain-coarsening temperature of forged 0.35–0.45% carbon steel was found to be above 1065° C. (3) With 0.10–0.12% of titanium and 0.05–0.15% of aluminium the grain-coarsening temperature of forged 0.35–0.40% carbon steel was higher than that required either by the addition of 0.1% of zirconium, or by increasing the aluminium alone from 0.10% to 0.15%. (4) There must be some titanium residual in the steel—deoxidation with titanium is not enough—to prevent the formation of coarse dendrites or to raise the grain-coarsening temperature; preliminary deoxidation with aluminium helps to retain the required titanium in the steel. (The percentages of titanium given are the residual contents, not the amounts added.)

**Development of Alloy Steels in Germany.** E. Houdremont. (Heat Treating and Forging, 1939, vol. 25, Aug., pp. 391-394). An abridged English translation of an article which appeared in *Stahl und Eisen*, 1939, vol. 59, Jan. 5, pp. 1-8; Jan. 12, pp. 33-39. (See Journ. I. and S.I., 1939, No. I., p. 238 A).

**Characteristics of 5.0 and 7.0 per cent. Chromium Steels with Varying Molybdenum and Vanadium Content.** W. G. Hildorf, C. L. Clark and A. E. White. (American Society for Metals, Oct., 1939, Preprint No. 8). The authors describe an investigation of the influence of variations in the molybdenum and vanadium contents of two types of chromium steels upon the tensile properties at room temperature and at 1200° F. The analyses of the steels tested varied between the following limits: Molybdenum 0.50-2.0%, vanadium 0-1.0% and chromium 5.0-7.0%. The results showed that the strength characteristics of the steels improved with increasing molybdenum content, whilst they tended to decrease with increasing vanadium content, especially when this exceeded 0.50%. At 1200° F. the same general trends were observed, although the changes were of a lower order of magnitude.

**Molybdenum Steel for Loeffler Boilers.** (Alloy Metals Review, 1939, vol. 2, Sept., pp. 73-74). The chemical and physical properties of a special steel are described. This steel was used for the superheater tubes of a Loeffler boiler installation, which are required to withstand a pressure of 2000 lb. per sq. in. at a temperature of 1000° F. This steel contains carbon 0.10-0.15%, silicon 0.15-0.25%, sulphur 0.04% max., phosphorus 0.04% max., manganese 0.4-0.6%, molybdenum 0.5-0.65% and chromium 0.7-0.9%.

**The Use of Steel in Heavy Works Plant.** W. Reid. (Metallurgia, 1939, vol. 20, July, pp. 125-126). The author remarks on the increased use of steel in place of cast iron for heavy machinery parts, describing by way of examples a 2500-ton wheel forging press, rolling-mill housings and frames for hydraulic presses.

## METALLOGRAPHY AND CONSTITUTION

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**A Metallographic Approach to the Study of the Sensitivity of Steel to Cold Work.** H. K. Work and S. L. Case. (Transactions of the American Society for Metals, 1939, vol. 27, Sept., pp. 771-779). The authors describe an investigation of methods of predicting the sensitivity of steel to cold-work with special reference to etching methods. They developed an etching technique using a modified form of A. Fry's reagent which produced strain lines in the specimens. It was found that ordinary broken tensile specimens, if examined near the break, fully answered the purpose of the test, since the amount of cold-work in the necked portion was sufficient to bring out essential differences in the response of various steels to the micro-etching procedure. The authors found that to obtain strain lines of maximum intensity the cold-worked specimen should be annealed at 600-800° F. The practical value of this technique lies in its ready applicability to thin-gauge materials, such as wire and strip, upon which certain of the more selective physical tests cannot be made.

**Heat Etching as a Means of Revealing Austenite Grain Size.** M. J. Day and J. B. Austin. (American Society for Metals, Oct., 1939, Preprint No. 33). The authors describe a simple and rapid method of etching by the application of heat which has proved useful in revealing the grain size of the austenite in steel. The method depends upon the preferential transfer of material away from the grain boundaries when the metal is brought to a high temperature in an inert atmosphere.

**The X-Ray Measurement of the Grain Size and of the Internal Elastic Stresses in Cold-Worked Sheets.** U. Dehlinger and A. Kochendörfer. (Zeitschrift für Metallkunde, 1939, vol. 31, July, pp. 231-234). After discussing theories concerning the widening of the end X-ray lines which has been observed in the radiographic examination of cold-worked metals, the authors consider to what extent this phenomenon is due to the minute size of the grains and to the lattice deformation. They describe the X-ray technique that they developed by which the distribution of both the first and the last Debye-Scherrer lines could be measured; from the data obtained by applying this technique to cold-rolled copper sheet they were able to calculate the degree of lattice deformation and the value of the internal stress.

**Grain-Size Control.** P. Mansini. (Australasian Engineer, 1939, vol. 39, Aug. 7, pp. 22-23, 27). After describing two methods of specifying the grain size of steel, namely the McQuaid-Ehn test and the Shepherd P-F (penetration-fracture) test, the author dis-

cusses how the grain size is affected by the temperature of heat treatment, hot-working and prior treatment. He also deals with the applications of fine- and coarse-grain steels, and in conclusion explains how the grain size can be controlled by the addition of such deoxidisers as aluminium, vanadium, titanium and zirconium.

**Grain Size of Steel.** N. F. Ward and J. E. Dorn. (*Metals and Alloys*, 1939, vol. 10, Mar., pp. 74-80; Apr., pp. 115-121; July, pp. 212-218; Aug., pp. 246-253). The authors discuss the technique of revealing the austenitic grain size in steel and review the literature on this subject. They then describe various methods of specifying the grain size with special reference to Shepherd's test, which is well known in America; in this connection they reproduce a photograph in which two series of ten fractures enable Jernkontoret's scale to be compared with that of Shepherd. The authors consider next the effect of the grain size of the austenite upon the properties of steel with special reference to the abnormal structure often found in slowly cooled steels. In conclusion they discuss various theories concerning the formation and growth of austenitic grains, particularly that of Grossmann and the adsorption theory of Benedicks and Löfquist. A bibliography of 100 references is appended.

**Note on the Structures Observed in Nickel Steels Cooled Very Slowly.** A. Portevin. (*Revue de Métallurgie, Mémoires*, 1939, vol. 36, July, pp. 316-321). The author discusses some structures of unusual type obtained in steels containing up to 12% of nickel and 0.2-0.7% of carbon by heating to about 1300° C. and cooling them very slowly for three days. He illustrates these structures by micrographs which reveal a feather-like structure associated with the constituents formed in the Ar'' transformation.

**The Mechanical Properties of the Isothermal Decomposition Products of Austenite.** M. Gensamer, E. B. Pearsall and G. V. Smith. (*American Society for Metals*, Oct., 1939, Preprint No. 26). The authors describe an investigation made with the object of relating the mechanical properties of steel to the presence and extent of the separate microstructural phases of which the steel is composed. The tests were made on specimens of  $\frac{1}{4}$ -in. and  $\frac{1}{8}$ -in.-dia. bridge wire containing 0.78% of carbon and 0.63% of manganese. These were heated in a lead bath to about 825° C., quenched in lead baths at various temperatures in the range 400-700° C. and then cooled slowly in a powdered refractory material. Tests were then made to determine the tensile, fatigue and cohesive strengths, and the interlamellar spacing of the pearlite was also measured. The authors discuss the results obtained, which are presented in graphs showing the relationship between these factors.

**The Influence of Microstructure upon the Process of Diffusion in Solid Metals.** F. N. Rhines and C. Wells. (*Transactions of the American Society for Metals*, 1939, vol. 27, Sept., pp. 625-656). The authors present some new observations on the diffusion of



metals and re-examine some of the published data with particular reference to the experimental methods which have been employed. They first examine the structural changes which accompany diffusion, showing that columnar grain formation occurs in systems involving a phase change. They find that recrystallisation, grain growth and twinning have been observed in the copper-zinc system, but not in single-phase alloys of chromium and nitrogen with iron. They are of the opinion that recrystallisation, grain growth and twinning may be induced by diffusion, chiefly when relatively large specific-volume changes are caused by the movement of the dissolved metal, that is, when the lattice-parameter change is larger and when the concentration gradient is steep. They study next the anisotropy of diffusion and discuss the theory that in the iron-carbon system the carbon diffuses less rapidly in fine than in coarse-grained materials. The present authors find, however, that there is a very small effect in the opposite sense. In the concluding part of their paper they consider the relative rates of intra- and intergranular diffusion. Although other investigators have concluded that, contrary to other systems, the intergranular diffusion of carbon in iron is slower than the intragranular diffusion, the present investigation of rates of decarburisation of iron and steel has shown a very slightly higher rate of intergranular diffusion.

**Study of Carbide Solution in Hypoeutectoid Plain Carbon and Low Alloy Commercial Steels.** R. H. Lauderdale and O. E. Harder. (Transactions of the American Society for Metals, 1939, vol. 27, Sept., pp. 581-607). The authors report on their investigation, which had as its object the determination of the rate of solution and the time necessary for the complete solution of the carbides in hypo-eutectoid steels at temperatures within and above their critical ranges, and to ascertain whether the carbides in hypo-eutectoid steels actually remain undissolved long enough to be effective in inhibiting the growth of austenite grains. The effect of time at various temperatures on the hardness developed in quenched specimens was also determined. The authors consider that the following conclusions seem to be warranted by their observations: (1) In the low carbon steels (carbon 0.17%) the carbide goes into solution quite rapidly at temperatures above the upper critical point and all the carbide disappears soon after the ferrite. In these steels not more than 8 sec. at 1700° F. were required for complete solution of the coarsely spheroidised carbides. (2) In the medium-carbon steels (carbon 0.30-0.40%) the relative rates of carbide and ferrite solution depend upon the testing temperature. Within the critical range it is possible to dissolve all the carbides and retain free ferrite. (3) The rapid rate at which the carbides go into solution in the low- and medium-carbon steels, even when coarsely spheroidised, and the short time required for the complete solution of the carbides seem to preclude the possibility of carbides in such steel inhibiting the coarsening of the austenite grains. (4) The

holding time before quenching necessary to develop full hardness in the small specimens used was remarkably short. The medium carbon steels developed full hardness after holding at 1600° F. for not more than 15 sec. (5) In the higher carbon steels (carbon 0.77 and 0.78%) the time required for enough carbon to go into solution to develop full hardness on quenching was quite short, *e.g.*, 1 to 2 sec. at 1600° F. and 5 to 7 sec. at 1500° F. (6) The only correlation which could be established between the grain coarsening of the higher carbon hypoeutectoid steels and the carbide solution was that after carburising for 8 hr. at 1700° and 1800° F. the steels tested showed McQuaid-Ehn grain sizes of 4-5 in both case and core, whereas it is known that the carbides go into solution at 1600° F. If the carbides effectively inhibited the grain growth it would be reasonable to expect a coarsening of the austenite grains as soon as the carbides had been dissolved. (7) The results obtained suggest that other factors, such as aluminium and nitrogen contents, may be more important than low alloy contents in controlling the coarsening of the carbides on long periods of heating at subcritical temperatures. (8) It is indicated that the size and distribution of the carbides are important factors in the behaviour of steels during heating for hardening. Large areas of free ferrite increase the time required for the ferrite to disappear. Large carbides go into solution more slowly than smaller ones, and this relation is conspicuous in the steels approaching the eutectoid composition. (9) Certain indications were found that the rate of carbon solution in the higher-carbon hypo-eutectoid steels is very rapid until enough carbon is in solution to produce full hardness in quenched specimens, but that the rate for further carbide solution is very much lower. (10) The data obtained indicate that the carbides in hypo-eutectoid steels do not play any important part in inhibiting the growth of the austenite grains.

#### **Kinetics of the Austenite to Martensite Transformation in Steel.**

A. B. Greninger and A. R. Troiano. (American Society for Metals, Oct., 1939, Preprint No. 25). The authors report the results of a microscopic study of the kinetics of the austenite-martensite transformation in plain carbon steel. The micrographs were taken of specimens quenched in baths at temperatures ranging from 260° to 100° C. in seven stages. The principal conclusions deduced from the results are: (1) If specimens of eutectoid steel are quenched in baths to successively lower temperatures, the formation of martensite is first observed when the steel is quenched to about 240° C. (2) For temperatures below 240° C. martensite is present a fraction of a second after the specimen reaches the temperature of the bath, and the amount of martensite is greater the lower the temperature of the bath. (3) Although the microscopic method of measuring the reaction rates is obviously incapable of great accuracy when the product of decomposition is as heterogeneous as it is in the temperature range studied in this investigation, it is certain

that any decomposition that may have occurred between 1 sec. and 5 min. at 200° C. is insignificant in comparison with the amount of martensite (25%) that is present immediately after the quenching temperature has reached 200° C. On the other hand, the McQuaid-Ehn S-curve shows that at 200° C. the austenite does not begin to decompose until after 2½ min. have elapsed. Again, the S-curve shows that decomposition at 140° C. does not begin for 15 sec., whereas the microscopic determination shows that a eutectoid specimen will contain about 50% of martensite by the time it has cooled to 140° C. The authors therefore consider that the S-curve showing the decomposition of austenite gives an incorrect picture of the austenite-to-martensite transformation, and that the older concept that the transformation only occurs during cooling through the proper temperature range is substantially correct.

**Transformation of Austenite on Quenching High-Purity Iron-Carbon Alloys.** T. G. Digges. (American Society for Metals, Oct., 1939, Preprint No. 24 : Journal of Research of the National Bureau of Standards, 1939, vol. 23, July, pp. 151-162). The author reports on an investigation undertaken primarily to show the influence of variation in the distribution and solution of carbon in austenite on the mode and rate of transformation of austenite in high-purity iron-carbon alloys. He found that with all the carbon in solution and uniformly distributed in austenite of mixed grain size, the initial transformation occurred at the grain boundaries. This austenite was least stable in the vicinity of its grain boundaries, where transformation occurred at a higher temperature than in the interior of the grains. With incomplete solution and non-uniform distribution in austenite of relatively large grain size, the transformation often proceeded at various rates within the grains. This was illustrated in an alloy containing 1.14% of carbon by the transformation products of one large grain of austenite. This grain transformed to cementite, ferrite, coarse lamellar pearlite, nodular troostite, and martensite. Hardness tests made on this decomposed grain of austenite showed a range of hardness from 190 Brinell for the soft pearlite to about 720 Brinell for the fully hardened martensite. The transformation rate of the alloys was influenced by the grain size of both uniform and non-uniform austenite with respect to carbon. With austenite of constant carbon content, uniformly distributed, the larger the grain size the more stable is the austenite. The temperature at the commencement of the Ar'' transformation decreased progressively with increase in carbon content of the alloys from about 900° F. with 0.23% of carbon to about 500° F. with 0.80% of carbon in the alloy.

**The Transformation of Austenite on Quenching.** (Metallurgist, 1939, vol. 12, Oct., pp. 75-76). The results obtained by T. G. Digges in his examination of the influence of variations of the distribution of carbon in austenite on the mode and rate of its transformation are discussed (*see preceding abstract*).

**The Spheroidizing of Steel by Isothermal Transformation.** P. Poyson, W. L. Hodapp and J. Leeder. (American Society for Metals, Oct., 1939, Preprint No. 27). The authors discuss the forms of heat treatment of plain carbon steels which produce lamellar pearlite and that required to produce spheroidised carbides. They describe an investigation which showed that to spheroidise these steels they should be heated to a temperature not far above the critical and quenched to a temperature not far below the critical, the carbon content being the factor which determines these temperatures. They also give details of heating cycles which they have evolved for producing spheroidised structures in carbon steels in much less time than that usually employed.

**Constitution Diagrams for Iron-Carbon-Molybdenum Alloys.** J. R. Blanchard, R. M. Parke and A. J. Herzig. (Transactions of the American Society for Metals, 1939, vol. 27, Sept., pp. 697-717). From the observations made by microscopic examinations and hardness tests on forty-one alloys the authors construct twelve constitutional diagrams of the iron-carbon-molybdenum system up to 1.2% of carbon and 6.0% of molybdenum. These diagrams show the structures found in the alloys when quenched in water from a series of temperatures between 1350° and 1850° F. and when normalised from the same temperatures. They find that, structurally, the primary effect of molybdenum appears to be to restrict the austenite grain growth. It strongly retards the transformation of austenite, thereby inducing high hardenability.

**Sigma Phase in Iron-Manganese-Chromium Alloys.** (Metallurgist, 1939, vol. 12, Oct., pp. 70-71). The resemblance of certain regions of the iron-manganese-chromium system to corresponding regions of the iron-nickel-chromium system is pointed out. Such resemblance is to be expected since manganese, like nickel, promotes the formation and stability of austenite in iron-chromium alloys, but is less effective for an equal concentration. The results obtained by P. Schafmeister and R. Ergang in their investigation of the  $\sigma$ -phase of the iron-manganese-chromium diagram up to 50% of manganese and 90% of chromium are discussed. (See Journ. I. and S.I., 1939, No. II., p. 44 A).



## CORROSION OF IRON AND STEEL

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**Researches on Corrosion in England.** J. C. Hudson. (Corrosion Conference, Paris, 19-24 Nov., 1938 : *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 22-41). In the course of his account of the progress of research on corrosion in England the author shows that the following seven aspects of the subject are being investigated : (1) The fundamentals of the theory of corrosion ; (2) methods of controlling the rate of corrosion ; (3) long-time tests ; (4) oxidation at elevated temperatures ; (5) fatigue and corrosion ; (6) protective coatings ; and (7) industrial research.

**The Arrangements for the Experimental Study of the Natural Corrosion of Steels in Ordinary Use.** M. Séguenot. (Corrosion Conference, Paris, 19-24 Nov., 1938 : *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 87-101). The author describes the organisation controlling the corrosion tests now being made in France by l'Office Technique pour l'Utilisation de l'Acier. (See Journ. I. and S.I., 1939, No. II., p. 178 A).

**The Present Position in Germany of Standardisation with Regard to Corrosion.** F. Tödt. (Corrosion Conference, Paris, 19-24 Nov., 1938 : *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 127-130). The author shows that in Germany standard methods of testing metals and paints and units for specifying the degree of corrosion have already been agreed upon. In addition "corrosion tables" have been drawn up in which the degrees of resistance of over 700 materials to the attack of various corrosive media are indicated.

**The Work of the Belgian Commission for the Study of Corrosion.** (Corrosion Conference, Paris, 19-24 Nov., 1938 : *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 102-104). The exact title of Committee No. 4 of the Belgian Association for the Study, Testing and Application of Materials (ABEM 4) is : *Commission pour la protection des aciers contre la corrosion à l'aide de peintures*. The classification of the paints used and the positions of the various testing stations in Belgium where the exposure tests are being carried out by the above committee are here reported. (See Journ. I. and S.I., 1939, No. II., p 178 A).

**Mechanical Strength and Corrosion.** J. Galibourg. (Corrosion Conference, Paris, 19-24 Nov., 1938 : *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 168-178). The author discusses the close relationship which exists between the mechanical strength and the corrosion of steel, and quotes the results of research which indicate the effect of stress on corrosion and the effect of corrosion on the mechanical properties.

**The Improvement of Long-Time Atmospheric Corrosion Tests.** W. Palmær. (Corrosion Conference, Paris, 19-24 Nov., 1938 : *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 61-62). In this brief discussion of long-time atmospheric corrosion tests the author points out that it is more important to know the duration of the periods when rain was falling than to know the total rainfall during the test. He also notes that corrosion does not occur at temperatures below 0° C. under ice or snow.

**Preliminary Experiences with Long-Time Corrosion Tests in the Natural Atmosphere.** G. Chaudron. (Corrosion Conference, Paris, 19-24 Nov., 1938 : *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 42-50). See *Journ. I. and S.I.*, 1939, No. II., p. 178 A.

**The Variation of the Rate of Rust Formation as a Function of Temperature.** W. Palmær. (Corrosion Conference, Paris, 19-24 Nov., 1938 : *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 59-60). The author describes some laboratory experiments on the corrosion of electrolytic pure iron and cast iron containing 3.8% of graphitic carbon from which he found that with both materials the rate of corrosion in saline increases by about 5% with 1° C. increase in temperature.

**A Study of the Behaviour of Metals and Alloys in Corrosive Media.** F. L. Laquë and O. B. J. Fraser. (Corrosion Conference, Paris, 19-24 Nov., 1938 : *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 137-144). The authors describe some corrosion tests carried out in the United States in which particular attention was paid to simulating industrial conditions as far as possible. In particular the effects of the rate of flow, the temperature and the degree of aeration of the attacking solutions were studied.

**A Study of the Rate of Dissolution of Mild Steel in Dilute Sulphuric Acid.** J. C. Hudson and T. A. Banfield. (Corrosion Conference, Paris, 19-24 Nov., 1938 : *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 286-291). See *Journ. I. and S.I.*, 1939, No. I., p. 69 A.

**The Effect of Cathodic Reactions on the Corrosion of Metals from the Viewpoint of the Local Cell Theory.** W. J. Müller. (Electrochemical Society, 1939, Sept., Preprint No. 28). The author discusses formulæ for studying the potentials of the cathodes and anodes in the electrochemical process of corrosion.

**Thermodynamics and Corrosion. The Rôle of the Potential and of the pH Value in Corrosion.** M. Pourbaix. (Corrosion Conference, Paris, 19-24 Nov., 1938 : *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 110-117). This paper has been previously published in *Métaux et Corrosion*, 1938, vol. 13, Nov., pp. 189-193. (See *Journ. I. and S.I.*, 1939, No. I., p. 193 A).

**The Use and Interpretation of Potential Measurements in Corrosion Researches.** T. P. Hoar. (Corrosion Conference, Paris, 19-24 Nov., 1938 : *Chimie et Industrie*, 1939, vol. 41, April Special

Number, pp. 118-124). The author discusses the application of measurements of the potential at the electrodes to corrosion research and examines the relationships between the potential, the condition of the oxide film, the porosity of the metal, the rate of corrosion and the action of inhibitors and accelerators.

**The Hydrogen Overvoltage in Particular on Cementite.** E. Palmær. (Corrosion Conference, Paris, 19-24 Nov., 1938 : *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 63-69). The author describes some experiments by which he determined the overvoltage of hydrogen on platinum, pure iron and cementite. He used very low current densities and found that the overvoltage is a constant the value of which depends upon the material. He found that the overvoltage for iron was  $0.06 \pm 0.0009$  V. and for cementite it was  $0.12 \pm 0.03$  V.

**Contribution to the Study of the Rôle of Inclusions in the Corrosion of Steel.** A. Portevin and L. Guitton. (Corrosion Conference, Paris, 19-24 Nov., 1938 : *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 249-259). In this study of the influence of the inclusions in steel on the rate of corrosion, the authors show that in most cases the influence is very slight, but the greater the electrical conductivity of the inclusions the greater is the rate of corrosion.

**The Intercrystalline Corrosion of Metals and Particularly that of Steel.** A. Fry. (Corrosion Conference, Paris, 19-24 Nov., 1938 : *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 350-362). The author analyses the causes of intergranular corrosion and describes suitable methods of heat treatment which will prevent it.

**The Influence of the  $\delta$ -Iron Content on the Intercrystalline Corrosion of the Austenitic Chromium-Nickel Steels.** R. Scherer. (Corrosion Conference, Paris, 19-24 Nov., 1938 : *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 363-370). The author discusses a number of heat treatment experiments with nickel-chromium steels which show that the rate of diffusion of the chromium in the austenitic nickel-chromium steels containing  $\delta$ -iron is much greater than in the 100% austenitic steels. He also describes a short-time heat treatment which by "regenerating" the metal tends to prevent intergranular corrosion.

**The Intercrystalline Corrosion of the 18/8 Stainless Steels. Remedies and Processes of Immunisation.** J. Wagner. (Corrosion Conference, Paris, 19-24 Nov., 1938 : *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 341-349). In his study of the intergranular corrosion of the 18/8 stainless steels the author finds that this corrosion is caused by the formation of compounds low in chromium between the grains at temperatures between  $425^\circ$  and  $850^\circ$  C. when more than 0.02% of carbon is dissolved in the austenite. He suggests two methods of preventing this type of corrosion, one based upon special heat treatment, and the other

upon the addition of an element which inhibits the formation of chromium carbide.

**Stress Corrosion Cracking of the Austenitic Chromium-Nickel Steels and its Industrial Implications.** J. C. Hodge and J. L. Miller. (American Society for Metals, Oct., 1939, Preprint No. 14). The authors investigated a type of failure which occurs in condenser and heat-exchanger tubes of austenitic 18/8 steel. The cracks lie in the direction of the service stresses, and sometimes occur in tubes quenched from high temperatures; the paths of the cracks are transcrystalline. Some of the failures involve a condition of internal static stress with simultaneous exposure to certain corrosive media which, in some cases, are so weak that they have no effect upon ordinary carbon steels. The authors found that the intensity of the stress, the strength of the corrosive medium and the susceptibility of the material to intercrystalline corrosion determine the path of the failure. To prevent this type of failure they recommend that the stresses set up in the fabrication of the unit of which the tube is a part be removed by some form of annealing.

**The Influence of Metallic Protective Coatings on the Resistance of Mild Steel to Fatigue in Air and to Corrosion.** R. Cazaud. (Corrosion Conference, Paris, 19-24 Nov., 1938: *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 381-384). The author compares the effects of zinc, cadmium, copper, nickel and chromium coatings on steel on its resistance to corrosion-fatigue in air and in soft water.

**A Rapid Test for Stainless Steels.** N. Goldowski. (Corrosion Conference, Paris, 19-24 Nov., 1938: *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 162-167). The author describes a rapid and convenient method of making corrosion tests on specimens of stainless steel using a solution of lithium chloride as the corroding medium.

**The Huey Test for the Corrosion Resistance of Welds in 18/8.** F. Meunier and H. Schnadt. (Corrosion Conference, Paris, 19-24 Nov., 1938: *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 222-230). The authors consider the suitability of the Huey corrosion test for determining the corrosion resistance of welds in 18/8 nickel-chromium steel.

**A New Modification of a Standard Salt-Spray Corrosion-Testing Apparatus.** J. Lucas and R. Colombet. (Corrosion Conference, Paris, 19-24 Nov., 1938: *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 153-155). The authors describe a new form of atomiser made of stainless steel and Monel metal for producing a fine salt spray for making corrosion tests. The apparatus works at a pressure of 100 mm. of mercury and the consumption of solution is only 50-60 c.c. per hr.

**The Quantitative Determination of the Onset of Corrosion on Iron.** F. Tödt. (Corrosion Conference, Paris, 19-24 Nov., 1938: *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 132-136).



The author describes a method of determining the exact moment when the corrosion of steel immersed in a weak corrosive medium commences and the rate of corrosion when this is very slow. The method is not based on the determination of the loss in weight, but on the determination of the amount of iron in solution; for this purpose the precipitating agent is a mixture of liquid ammonia and sodium sulphide solution.

**A Test of the Corrosion Resistance of Tinplate.** G. Gire. (Corrosion Conference, Paris, 19-24 Nov., 1938 : *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 156-159). The author describes a method of determining and specifying the corrosion resistance of tinplate. In this method he studies the dissolution of the tin and the steel in relation to time, and from the data obtained he establishes a coefficient of resistance which is the maximum quantity of tin dissolved divided by the amount of iron dissolved when this point is reached.

**Some Conclusions from an Experimental Study of the Corrosion of Welds.** A. Portevin and A. Leroy. (Corrosion Conference, Paris, 19-24 Nov., 1938 : *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 234-239). See *Journ. I. and S.I.*, 1939, No. II., p. 111 A.

**Some Results Relative to the Corrosion of Mild Steel by Nitrates.** E. Herzog and A. Portevin. (Corrosion Conference, Paris, 19-24 Nov., 1938 : *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 471-473). The authors report the results of some tests of the corrosion of stressed steel specimens by solutions of calcium and ammonium nitrates. The specimens examined included mild steel, 5% nickel steel and chromium-aluminium steel.

**Corrosion of Metals in the Manufacture of Phosphoric Acid by the Electric Furnace Process.** C. E. Hartford and R. L. Copson. (*Industrial and Engineering Chemistry, Industrial Edition*, 1939, vol. 31, Sept., pp. 1123-1128). The authors discuss the acid-corrosion problems which have arisen at a works in the Tennessee Valley manufacturing phosphate fertilisers. They describe a programme of testing samples of carbon and alloy steels and non-ferrous metals under actual plant conditions and present tables showing the amounts lost by corrosion and the analyses and position of the specimens. They found that in crude concentrated phosphoric acid the lowest rates of corrosion were shown by the cast nickel alloys containing large percentages of silicon, chromium or molybdenum. The next lowest rate was shown by the cast silicon-iron alloys; the other ferrous alloys offered resistance to the attack of phosphoric acid in the following order of decreasing resistance: The chromium-nickel-molybdenum low-carbon steels, the 18/8 chromium-nickel steels and the 26-30% chromium steels. The copper alloys ranked just below the best of the ferrous alloys.

**Some Aspects of Corrosion in a Petrol Refinery.** J. Moinard and

P. Moyne. (Corrosion Conference, Paris, 19-24 Nov., 1938 : *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 477-481).

**The Internal Corrosion of Boiler Tubes and of Superheaters in Marine Boilers.** M. David. (Corrosion Conference, Paris, 19-24 Nov., 1938 : *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 463-470). The author examines the two principal causes of the corrosion of the inner surface of boiler and superheater tubes ; these are the presence of (a) salts or acids, and (b) dissolved oxygen in the feed water.

**The Protection of Steel Tubes against Electric Currents. Tests and Practical Applications.** O. Scarpa. (Corrosion Conference, Paris, 19-24 Nov., 1938 : *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 70-77). After describing the corrosion of iron and steel pipes by stray currents, the author reports on some laboratory tests which showed that burying the pipes in cement with a layer of paper impregnated with bitumen between the pipe and the cement provided complete protection.

**A Contribution to the Study of the Corrosion Resistance of the Semi-Rust-Resisting Steels.** A. Petiniaud. (Corrosion Conference, Paris, 19-24 Nov., 1938 : *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 447-452). The author discusses the results of a series of tests of the corrosion of copper-bearing steel in salt spray, sea water and sulphuric acid.

**The Semi-Rust-Resisting Steels and Their Resistance to Natural Waters.** E. Herzog. (Corrosion Conference, Paris, 19-24 Nov., 1938 : *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 453-459). The author discusses the results of a series of tests in which the corrosion-resisting properties of mild steel and of steel containing 3% of chromium + aluminium in sea water and soft water are compared.

**Contribution to the Study of the Corrosion of Iron and Steel by the Committee of the Institution of Civil Engineers Charged with the Study of the Deterioration of Structures in Seawater.** (Corrosion Conference, Paris, 19-24 Nov., 1938 : *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 105-109). Since 1920 the Institution of Civil Engineers in collaboration with the Department of Scientific and Industrial Research has been carrying out a series of long-time tests on the effects of sea water on metals, wood and cement under various climatic conditions. The results of the tests during the period 1920-1930 on iron and steel specimens are here briefly examined and discussed.

**Results and Practical Interest of Laboratory Tests on Corrosion in Salt Solutions.** G. D. Bengough and F. Wormwell. (Corrosion Conference, Paris, 19-24 Nov., 1938 : *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 78-86). The authors discuss the results of a number of accelerated corrosion tests on specimens of mild steel completely immersed in different salt solutions. These

results are in close agreement with those obtained by J. Newton Friend in long-time tests in sea water at various docks and ports.

**The Rusting of Iron by Drops of Water under a Liquid Immiscible with Water.** P. Ronceray. (Corrosion Conference, Paris, 19-24 Nov., 1938 : *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 179-181). The author describes some experiments made to establish what influence dust has upon the formation of rust on commercial iron.

**The Effect of the Treatment of Water on Corrosion.** U. R. Evans. (Corrosion Conference, Paris, 19-24 Nov., 1938 : *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 492-496). See *Journ. I. and S.I.*, 1939, No. I., p. 68 A.

**Some Notes on Ship Corrosion and Paint.** H. E. Skinner. (Transactions of the Institution of Naval Architects, 1939, vol. 81, pp. 317-324). The tendency is for modern ships to corrode more rapidly than is desirable, and much money is spent in repairing the ravages of rapid pitting, the most troublesome form of corrosion to which portions of the ship in contact with liquid are subjected. A special example of this type of attack is analysed to try to determine the cause, and it appears that the possible agent is free electricity. Pictorial evidence is given of the similarity in attack on steel electrodes immersed in sea water with an electric current flowing. Further specimens coated with the usual protective paints or galvanised, also with zinc protectors and given similar treatment, show the weakness of these familiar protectors against electrical action. On the basis of an experiment performed during some ship trials evidence is given that free electricity can be present in ships. This suggests the conclusion that rapid pitting is due to electrical action, and consequently, in view of the tests performed, protective paints are of little use in arresting this special form of corrosion. Since all corrosion is generally electrical in origin, a paint resistant to electrical attack is a more effective protection against corrosion than those at present in use.

**A Study of Protective Coatings and Their Formation.** A. Portevin and E. Herzog. (Corrosion Conference, Paris, 19-24 Nov., 1938 : *Chimie et Industrie*, 1939, vol. 41, April Special Number, pp. 260-270). The authors study the formation of oxide films on steels containing small percentages of copper, chromium, nickel or aluminium by means of chemical analyses, magnetic tests and potential determinations.

**The Effect of Humidity of Air on the Oxidation of a Low Carbon Steel.** C. A. Siebert and H. G. Donnelly. (American Society for Metals, Oct., 1939, Preprint No. 32). The authors investigated the different degrees of oxidation of a 0.14% carbon steel containing chromium 0.07% and nickel 0.14% in moist air and in dry air in the temperature range 995-1175° C.

## BOOK NOTICES

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COOKSON, W., and A. BOLD. "*The Elements of Sheet-Metal Work.*" 4to, pp. viii + 117. Illustrated. London, 1939. The Technical Press, Ltd. (Price 6s.)

Construction in sheet metal is one of the main divisions of the metal fabrication industries, and, having extensive applications at the present time, it has become a highly technical subject. Any book which sets out to deal in full with all that pertains to modern sheet-metal work would have to be very extensive, but the present work is much less ambitious in its aims. Like moulders, pattern-makers, welders, smiths, heat-treaters and numerous other tradesmen in the metal industries, sheet-metal workers require a certain amount of technical instruction to supplement the knowledge they acquire from practical experience, and it is for them that this book has been written. It is addressed to journeymen, draughtsmen, improvers, apprentices, students and all interested in pattern development and the working up of sheet-metal. Some of the chapters deal with arithmetic, geometry and mensuration, the properties of metals, and metallurgical processes such as galvanising, tinning, annealing and normalising, but the main portion of the book is devoted to the consideration of pattern layout and development, workshop tools and appliances, methods of working the sheet to the required shape and joining by riveting, brazing, welding, &c. As will be seen, the scope of the book is limited to what may be described as hand operations, and it does not pretend to discuss dies, presses or press operations.

J. M. ROBERTSON.

HANEMANN und SCHRADER. "*Atlas Metallographicus.*" Band II., Lieferung 7, Tafel 49-56; Lieferung 8, Tafel 57-64. Berlin, 1939. Gebrüder Borntraeger. Price 9.00 and 12.00 RM. respectively.

Both of these issues deal with various aspects of the structure of cast iron. The first part under review is concerned with the structural modifications produced in simple cast irons by various heat treatments. No general text is included in this part, the only descriptive matter being the notes accompanying the illustrations. The micrographs of heat-treated irons suggest that many of the structural changes can accurately be foretold from a knowledge of the corresponding changes in carbon steel, but this method is not of universal application, and in grey irons the presence of graphite in the structure introduces a factor that has no counterpart in steel. The authors account satisfactorily for the presence of massive ferrite adjacent to the graphite flakes in slowly cooled grey irons. They attribute it to the tendency for the stable graphite-ferrite eutectoid to form, the graphite coalescing with the pre-eutectoid graphite and leaving the ferrite isolated. This explanation appears to be the most acceptable of all those proposed to account for this rather obscure phenomenon. Other sections of this part cover the micrographic characteristics of the primary and eutectic constituents of white irons.



Part 8 concludes Volume II., and contains very full indices by means of which it should be relatively simple to locate any item or to search for information on any general aspect of the structure of cast iron. In this part is also included the final section of text concerning grey cast iron and the complete text on chilled and white irons. The annealing (malleablising), growth, and hardening of grey iron are described, and the various factors affecting the chill or "whiteness" of irons are discussed. The micrographs in this part illustrate chiefly the effect of different conditions on the chilling of semi-white iron, but some micrographs of minor metallographic features, such as the configuration of the phosphide eutectic and of manganese sulphide in white irons, are also given.

The concise text will be of interest to many besides metallographists, to whom, naturally, the fine micrographical reproductions will specially appeal. Contrary to the usual scientific text-book, the micrographs here are not mere illustrations, they are the framework round which the text is written, and certainly Volume II., now completed, has left little or nothing in the structure of cast iron to the imagination.

STEPHEN L. ROBERTON.

MOON, A. RAMSAY. "*The Design of Welded Steel Structures.*" 8vo, pp. viii + 140. Illustrated. London, 1939. Sir Isaac Pitman and Sons, Ltd. (Price 15s.)

Although the literature on welding is now very extensive, much of it is concerned with the application of different methods to different materials, with descriptions of specific examples of welded construction, with tests of the properties of weld metal and with methods of inspection. There is evidently a need for a short and simple text-book describing how welding may most effectively be used in work for which it has obvious advantages, and it is to supply this that the present book has been written. Its scope is limited by its size, but it presents a very useful account of the elements of design and technique relating to the metal-arc welding of constructional steelwork. After a brief description of the welding characteristics of mild steel, high-tensile steel, high-carbon steel, wrought iron and cast steel, the author proceeds to deal with the principal types of welding electrodes, the physical properties of welds made with the different electrodes, the selection of electrodes and welding procedure. All this is very brief, of course, as the whole chapter concerned occupies only nine pages. The next chapter deals with weld forms, *e.g.*, butt and fillet welds, preparation for welding and the process of failure of weld forms. Following this, two chapters are devoted respectively to stresses in welds and welded joints, and design data. In this latter chapter there are sections on the strength of single-run fillet welds and the probable variation in the strength of welds. The remainder of the book, *i.e.*, six chapters, is concerned with design. Attention is given in the first place to the design of typical joints, then to the design of structural units, then to steel-frame structures and roof trusses. The last chapter deals with welding in reinforced-concrete construction. A number of plates show in detail the construction of certain structural units and roof trusses. From this brief description it will be seen that the principal object of the book is to explain the proper use of metal-arc welding in the construction of steel-frame buildings, and within the available space a useful account is included by omitting descriptions of other methods and other applications.

J. M. ROBERTSON.

REAMS, C. E. "*Modern Blast Cleaning and Ventilation.*" First ed. 8vo, pp. xiii + 213. Illustrated. Cleveland, Ohio, 1939. Penton Publishing Co. (Price 22s.)

This is apparently the first book to be published on the subject of cleaning by abrasive blasting, and as it deals comprehensively with all aspects of the subject, it should prove a welcome addition to metallurgical literature from the point of view of the large number of people who are concerned either directly or indirectly with metal cleaning. For its size the book contains a surprising number of chapters, and the average length of the thirty-five chapters is less than six pages. As the subjects considered in each chapter are given in detail in the table of contents, any required item can be located with moderate ease. There is also an index. The first chapter, on the history of blast-cleaning, is followed by one on abrasives, *i.e.*, steel shot and grit, sand and other abrasives. Following this there are chapters on the principles of compressed-air blast-cleaning, the separation and recovery of abrasives, nozzles and abrasive pipe-lines. After these there are chapters on pressure, and the effect of moisture in compressed air, then a series of chapters on the various types of blast-cleaning equipment, *i.e.*, manual, barrel, table and automatic types. The installation of compressors and accessory equipment is then considered, and after that attention is given to low-pressure blasting, centrifugal blasting and ventilation (four chapters). In this part a chapter is included on the effect of surface blasting in increasing the fatigue resistance. Various other aspects of the subject, such as the reduction of industrial hazards, hydroblasting, the selection and maintenance of equipment, &c., are then considered, and the book concludes with a series of chapters on the applications of blast-cleaning to rolled steel, cold-mill rolls, forgings, special alloys and tools, and metals intended for enamelling or metal-coating. Throughout the book there are some lengthy tables giving, for example, the abrasives selected for various kinds of work, cleaning costs, &c., and in the appendix there is a long list of uses for blast-cleaning equipment. This last table must have taken some trouble to compile, and in view of the fact that once the process has been shown to be applicable to certain metals or components its use with others could be inferred, the preparation of such an extensive table of assorted uses seems hardly worth while.

J. M. ROBERTSON.

## MINERAL RESOURCES

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**Significance of the Iron Oxide Outcrop of Mount Oxide, Queensland.** R. Blanchard. (Proceedings of the Australasian Institute of Mining and Metallurgy, 1939, No. 114, June 30, pp. 21-50). The iron oxide outcrop overlies in part the rich chalcocite ore-body at Mount Oxide which lies about 45 miles north-west of Dobbryn, the terminus of the Queensland Government railway. It has been contended that this outcrop represents the residual of an original medium-to-low-grade primary copper pyrites mass, from which the adjoining chalcocite ore-shoot has been derived by leaching. In this paper the author examines the validity of this contention.

**Magnetic Observations in the Onekaka-Parapara District, with Some Remarks on the Geology of the Iron-Ore Deposits.** W. M. Jones. (New Zealand Journal of Science and Technology, 1939, vol. 21, July, pp. 16B-30B). The author describes the results of some magnetic and other observations made in 1937 and 1938 on the Onekaka-Parapara iron-ore deposits and over the surrounding country between Takaka and Bainham in the north of the South Island of New Zealand. The survey was made with the object of finding whether this geophysical method would supply further information on the extent, structure and origin of the ores. The author discusses the magnetic effects and their possible relations to the origin and structure of the ore-bodies.

**Manganese.—A Key Metal in the Manufacture of Iron and Steel.** (Metallurgia, 1939, vol. 20, Oct., pp. 197-198). The occurrence and classification of manganese ores throughout the world and the applications of manganese in both the ferrous and non-ferrous metal industries are discussed.

## ORES—MINING AND TREATMENT

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**Ironstone Mining in Cleveland.** J. R. Tomlinson and J. C. Dack. (National Association of Colliery Managers: Iron and Coal Trades Review, 1939, vol. 139, Sept. 29, pp. 431-434). The authors review the occurrence and origin of Cleveland ironstone (in Yorkshire) and refer briefly to its early history.

**Iron-Ore Extraction in the Midlands.** (Iron and Coal Trades Review, 1939, vol. 139, Sept. 8, pp. 331-333). A summary is presented of the Report of the Committee on the Restoration of Land Affected by Iron Ore Working. This report describes the methods used by Stewarts and Lloyds, Ltd., for winning the iron ores from their ore beds in Northamptonshire. With regard to the area of land devastated by dumping the over-burden, the Committee find that, in the Midlands, at present less than 200 acres are devastated per annum, and this area is not expected to rise to 300 acres within the next twenty-five years.

**Present-Day Problems Confronting the Swedish Mining Industry.** J. Kempe. (Jernkontorets Annaler, 1939, vol. 123, No. 7, pp. 285-295). (In Swedish). The author reviews the developments which have taken place during the last five years in the Swedish iron-ore industry as a result of its endeavours to supply ores for export at competitive prices. The factors which have increased the costs of production in Sweden are: (a) Increased wages and better standard of living; (b) the increased cost of materials; (c) the increased cost caused by the increased depth of mining; and (d) increased social charges and taxes. The developments to which the author refers include: (1) The use of the "X" pneumatic boring machine of the Diamantborrningsbolag; (2) increasing the air pressure of drilling machines from 7 to 12 kg. per sq. cm.; (3) changing from manual to mechanical haulage, in particular the use of the drag-line system; (4) the use of Diesel locomotives instead of compressed air or electric locomotives, both above and below ground; (5) the use of light-alloy skips and cages so as to decrease the tare loads on winding engines; (6) the increased application of the flotation process of ore concentration; and (7) measures to reduce the number of accidents.

**The Mines of the Fortuna Syndicate in the Salzgitter Hills and the Ore-Treatment Processes in Use There.** K. Kaup. (Stahl und Eisen, 1939, vol. 59, Oct. 26, pp. 1169-1173). The author describes the methods of mining and ore-concentration employed at the Fortuna, Morgenstern, Ida and Bismarck mines in the Salzgitter Hills.



**Heat Balances and the Economics of Ore-Preparation Plants.**

**I. Shaft and Rotary Furnaces, Sintering Plants.** K. Guthmann. (Stahl und Eisen, 1939, vol. 59, Oct. 12, pp. 1125-1133). The author discusses the heat balances and fuel consumption of the roasting and sintering plants used in Germany for the preparation of low-grade ores.

**The Magnetic Properties of Roasted Spathic Iron Ore and Their Improvement by Changed Conditions of Roasting.** W. Luyken and L. Heller. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1939, vol. 21, No. 18, pp. 271-288). The authors report on a number of experiments with spathic iron ores from Siegerland, Styria and Czechoslovakia in which they determined the effects of the roasting time and temperature on the magnetic properties of the concentrate. They made an X-ray study of the structure of the concentrate produced by roasting artificially-produced iron carbonate. They also compared the concentrate produced by roasting and cooling the ore in an atmosphere rich in carbon dioxide with that produced by (a) magnetising-roasting in a small laboratory rotary kiln taking a 1.5 kg. charge, and (b) a larger rotary kiln with a capacity of 30-40 kg. per hr. The results of these tests proved that magnetising-roasting in a rotary kiln offers several advantages over roasting in a shaft kiln.

**The Adsorption, Flocculation and Flotation of Certain Mineral Oxides.** G. G. Bring. (Jernkontorets Annaler, 1939, vol. 123, No. 6, pp. 229-264). (In Swedish). The minerals apatite, specular iron ore and quartz, which are always present in the Swedish red hematite ores, are particularly interesting from the flotation point of view, as they behave quite differently. Apatite floats readily in solutions of fatty acids and of fatty-acid salts; specular ore also floats in fatty-acid solutions, but not so readily as apatite, and so will quartz, especially if it can be flocculated. In this paper the author gives an account of a laboratory investigation undertaken to determine the quantities of fatty-acid salts which, when in contact with solutions and stirred, will be adsorbed by the above three minerals. He found that apatite adsorbed the most and quartz the least, and that the coarsely-grained material adsorbed much more per unit of area than did the finely-grained material. He also made flotation experiments with these minerals and the same reagents as in the adsorption tests. His results varied with the experimental conditions, but generally speaking, the specular ore and the apatite floated better than the quartz, but the author did not establish any definite relationship between the adsorption and the flotation. The quantity of reagent used in the flotation process was very much less than the quantity adsorbed in the corresponding adsorption test. He also studied the flocculation of these minerals during the flotation process, and found that the rate of flotation greatly increased at the commencement of flocculation, but the flotation decreased with strong flocculation.

## REFRACTORY MATERIALS

(Continued from pp. 1 A-2 A)

**Magnesite.** A. W. Comber. (Twenty-second Streatfield Memorial Lecture before the Institute of Chemistry, Oct., 1939). The author devotes the greater part of this paper to an account of the mineralogy, distribution, origin and formation of the various forms of magnesite throughout the world, and also gives some consideration to those forms which are used for the manufacture of refractory bricks.

**Reactions of Slag with Refractories : II. Refractory Coatings Produced with Metallic Aluminium.** H. G. Schurecht. (Journal of the American Ceramic Society, 1939, vol. 22, Nov., pp. 384-388). In the second part of his study of the action of slag on refractories (*see* Journ. I. and S.I., 1939, No. II., p. 60 A) the author reports the results of some experiments made to determine the effect of spraying molten aluminium and a slip containing clay and aluminium powder on firebrick. He found that exothermic reactions took place, commencing in the range 750-930° C., in the course of which the temperature of the coating rose to about 1500° C. in 5 min. Such coatings increased the resistance of the bricks to attack by basic slags, but decreased their resistance to acid slags.

**Steelworks Refractories in Services. Part I. A Method of Allocating Refractories Consumption in the Open-Hearth Furnace.** J. C. Hayman. (Transactions of the British Ceramic Society, 1939, vol. 38, Oct., pp. 529-535). The author describes the system employed for allocating the consumption of refractories in the steel furnaces at the various plants of Guest Keen Baldwins Iron and Steel Co., Ltd. The system is designed to provide a ready means of correlating the qualities of refractory with the service obtained in each section of the open-hearth furnace, and it includes the procedure for presenting these data periodically in the form of furnace campaign cost reports.

**Steelworks Refractories in Service. Part II. The Evaluation of Basic Refractories.** J. C. Hayman. (Transactions of the British Ceramic Society, 1939, vol. 38, Oct., pp. 536-553). The author discusses some of the observations and deductions made concerning the use of refractories in open-hearth furnaces by the system previously described (*see* preceding abstract). He finds that there is a correlation between service and laboratory tests on two brands of chrome-magnesite brick. The laboratory tests included an iron-oxide absorption test, the technique of which is described. The trial of two brands of brick was made in the front walls of 70-ton fixed furnaces. The author points out that the use of chrome-magnesite

in place of silica and magnesite in this position was decidedly advantageous from the standpoint of cost. Chrome-magnesite bricks were also found to be more economical than silica bricks in the gas ends of a fixed furnace, but in the furnace blocks severe disintegration due to iron-oxide absorption, accompanied by fusion of portions of the chrome-magnesite, brought about early failure. An examination of various samples of used brick strongly indicated that slag attack on superincumbent silica work had also played an important part in the observed fusion of the chrome-magnesite. The research also indicated that the fusible material draining from the chrome-magnesite bricks had a corroding effect on the silica bricks used at lower levels in the uptake.

**The Life of Acid Furnace Bottoms.** V. Maksimov. (Stal, 1939, No. 4-5, pp. 18-19). (In Russian). Examination of the bottoms of acid open-hearth furnaces which had proved unsatisfactory showed that this was due to the use of high-silica sand. The practice of adding 5% of clay containing 50.0-52.5% of silica to the sand was adopted, and this resulted in better resistance of the bottoms.

## FUEL

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(Continued from pp. 3 A-5 A)

**The Transfer of Heat in Tubes and Clusters of Tubes.** A. Schack. (Archiv für das Eisenhüttenwesen, 1939, vol. 13, Oct., pp. 155-169). The author reviews the results of recent investigations on the determination of the rates of heat transfer at high temperatures from gases passing through the inside of a tube and over the outside of a cluster of tubes.

**Application of Heat Transfer Data to Furnace Walls and Roofs.** F. A. Faville and G. Ellerton, jun. (Iron and Steel Engineer, 1939, vol. 16, Oct., pp. 60-68). The authors discuss the formulæ and graphs which can be used for calculating the heat losses from furnace walls, and give some examples of their application with respect to the determination of the thicknesses of refractory brick and insulating material in steel-furnace roofs.

**Coal Preparation at Glass Houghton and Castleford Collieries.** (Iron and Coal Trades Review, 1939, vol. 139, Nov. 10, pp. 653-655). An illustrated description is given of the Barvoys coal-washing plant recently installed at the Glass Houghton and Castleford Collieries for the cleaning of coals between  $\frac{5}{8}$  in. and 8 in.

**Installation of a New Coal Washer at the André Dumont Colliery at Waterschei.** F. Lantin. (Revue Universelle des Mines, 1939, vol. 15, Oct., pp. 519-526). The author presents a full description, with diagrams and illustrations, of the coal-washing plant completed in 1938 at the André Dumont Colliery, Waterschei, Belgium. The plant, which has a capacity of 200 tons per hr., separates coal in the 0-80 mm. range into seven sizes by a wet process using vibrating screens.

**Carbonizing Properties and Petrographic Composition of Pond Creek-Bed Coal from Majestic Mine, Majestic Pike County, Ky.** A. C. Fieldner, J. D. Davis, W. A. Selvig, D. A. Reynolds and H. S. Auvil. (United States Bureau of Mines, 1939, Technical Paper No. 596).

**Experiments on Coking Properties of Coal.** H. W. Jackman. (Michigan Gas Association, June, 1939: Gas Journal, 1939, vol. 228, Oct. 11, pp. 84-85). The author discusses the results of some small-scale tests on the coking properties of some West Virginian coals. From these results he concludes that in coke-oven practice producing domestic coke from high-volatile coal, a coke with a density of at least 1.80 has a hard structure, one with a density of 1.75-1.80 is medium-hard, and one with a density under 1.75 is soft. His investigation of the relationship between the carbonisation



temperature and the porosity, density and burning rate of the coke produced showed that these properties remained fairly constant for carbonisation temperatures from 2000° F. down to a point between 1800° and 1600° F., but below 1600° F. the coke becomes much softer and burns much faster.

**The Physical Principles of Benzol Wash-Oil Distillation and Their Application to the Design of Benzol Distillation Towers.** C. Koepfel. (Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte Konzerns, 1939, vol. 7, Oct., pp. 169–183). In this mathematical discussion the author considers the physical properties of benzol wash-oil mixtures and applies these to calculations respecting the design and efficiency of fractional distillation towers in benzol refineries.

**A New Method of Supervising Open-Hearth Furnaces Fired with Carburetted Coke-Oven Gas.** C. Kreutzer. (Stahl und Eisen, 1939, vol. 59, Sept. 7, pp. 1017–1026). The author discusses the carburetting of coke-oven gas with powdered brown coal as a means of increasing the efficiency of this fuel for the firing of open-hearth furnaces. He considers in particular the effects of change in the rate of addition of the brown coal, the cutting action of the fuel on the furnace roof and means of preventing it, the methods of making a temperature survey of the flame and of the roof-lining, and the furnace efficiency achieved in practice in the manufacture of carbon and of alloy steels.

**Silesia and the Supply of Long-Distance Gas.** L. Segelken. (Stahl und Eisen, 1939, vol. 59, Sept. 28, pp. 1082–1087). The author discusses the economic aspects of the proposed construction of a system of long-distance gas supply in Upper and Lower Silesia.

**Hydrogenation of the Banded Constituents of Coal.** C. H. Fisher, G. C. Sprunk, A. Eisner, L. Clarke and H. H. Storch. (Industrial and Engineering Chemistry, Industrial Edition, 1939, vol. 31, Sept., pp. 1155–1161). Following an earlier investigation of the behaviour of the fusain in coal during hydrogenation (*see* Journ. I. and S.I., 1939, No. I., p. 335 A), the authors now report on the results of laboratory tests to ascertain the behaviour of the vitrains of different rank and of the different components of the attritus (spores, resins, oil algæ, translucent attritus and opaque matter), and discuss how the presence of these components influences the yield of hydrocarbons obtained from the coal by hydrogenation.

**Production of Liquid Fuel.** H. Stevens. (Chemical Age, 1939, vol. 41, Sept. 23, pp. 225–226). The author briefly describes a form of electric carbonising retort which has been successfully operated in America. He suggests it could be used with advantage in Great Britain to increase the supply of home-produced liquid fuel. The process has been previously described (*see* Journ. I. and S.I., 1939, No. II., p. 64 A).

## PRODUCTION OF IRON

(Continued from pp. 6 A-8 A)

**The Standard Depth of the Hearth of a Blast-Furnace.** V. I. Kotov. (Metallurg, 1939, No. 6, pp. 13-18). (In Russian). Examination of the characteristics of a number of large Russian and foreign blast-furnaces, together with a discussion of the effect of the height and volume of the hearth on the operation of the furnace, leads the author to the following conclusions regarding a deep hearth: (1) It improves the capacity of the furnace to burn fuel, *i.e.*, it increases the output capacity; (2) it decreases, at all times, the resistance to the blast, *i.e.*, reduces blowing costs; (3) it favours desulphurisation of the pig iron; (4) it protects the furnace bottom from attack by the molten metal; and (5) it simplifies slag tapping.

**Rapid Complete Repair of a Blast-Furnace.** N. Kratenko. (Stal, 1939, No. 3, pp. 1-12). (In Russian). Full details relative to the complete repair of the No. 3 blast-furnace of the Kuznetskiy works are given. These include the preparatory work, and the repair of the furnace itself and accessory mechanical, electrical and other equipment, and reference is made to materials, labour requirements and costs. Before the repair, the furnace had been worked for 1599 days, producing 1,684,227 tons of pig iron, with only two minor repairs. The drying of the lining was commenced 29 days after the beginning of the repair. Wood was used for the preliminary drying, after which the hot blast was turned on.

**Investigation of the Working of the No. 3 Blast-Furnace at the Zaporozhstal Works.** I. Kozlovich. (Stal, 1939, No. 4-5, pp. 1-7). (In Russian). The No. 3 furnace dealt with has a useful capacity of 1300 cu. m. The author describes preliminary tests on the distribution of the burden in the furnace, which were made in the first production period. During the construction of the furnace small openings were left in the casing and lining to facilitate sampling. The tests described, which covered a five and a half months' campaign, included analyses of gas samples from various parts of the furnace, flue-gas analyses, analyses of the burden at various points to determine the progress of the reduction, and measurements of the gas pressure and temperature distribution within the furnace.

**Influence of the Nature of the Coke on the Depth of the Oxidising Zone in the Hearth of the No. 2 Blast-Furnace at the Kuznetskiy Works.** D. S. Khorunov and S. A. Toforov. (Metallurg, 1939, No. 4-5, pp. 35-43). (In Russian). Data relating particularly to the composition of gas samples taken through one of the tuyeres

of the No. 2 blast-furnace at the Kuznetskiy works, together with analyses of metal and slag, are presented. The general conclusion reached was that the depth of the oxidising zone increased with the drum-test figure for the coke used in the burden at the time.

**The Blast-Furnace Process.** L. F. Wright. (Proceedings of the Cleveland Institution of Engineers, 1938-1939, No. 4, pp. 134-162). The author discusses the blast-furnace process with special reference to the economical utilisation of fuel. He illustrates his theories with data obtained under conditions which permitted a free selection of ores and cokes and during the production of many classes of pig iron.

**Research on the Production of Metals by the Application of Heat.** E. J. Kohlmeyer. (Metall und Erz, 1939, vol. 36, Nov., No. 22, pp. 545-551). The author studies how the laws governing rates of heat transfer, reaction velocities, combustion, evaporation and reduction can best be applied with the object of improving processes for the production of metals.

**The Coke Consumption, Material- and Heat-Balance of Blast-Furnaces, with Special Reference to the Smelting of Low-Grade Ores.** F. Wesemann. (Archiv für das Eisenhüttenwesen, 1939, vol. 13, Sept., pp. 113-122). The author considers the relationships between the heat balance and the coke consumption of a blast-furnace, dividing the latter into the requirements for heating and for reducing the ore. He compares the calculated coke consumption with results achieved in practice and also examines the relationships between the blast consumption, the coke consumption and the indirect reduction. The figures he quotes relate to the reduction of low-grade Salzgitter ore.

**The Effect of Gaseous Accompanying Elements on the Dissociation of Carbon Monoxide.** W. Baukloh and E. Spetzler. (Archiv für das Eisenhüttenwesen, 1939, vol. 13, Nov., pp. 223-226). In a series of laboratory tests the authors studied how the dissociation of carbon monoxide was affected by carbon dioxide, nitrogen, steam and water vapour in the presence of metallic iron. They observed that hydrogen greatly accelerated the decomposition at high temperatures. Steam, on the other hand, had a retarding effect. They made additional tests using a mixture consisting of carbon monoxide 27%, carbon dioxide 14%, nitrogen 56% and hydrogen 3%, to represent the action of blast-furnace gas and concluded from the results obtained that the decomposition was greatest in the temperature range 400-650° C.

**X-Ray Study of the Products of Reduction of Titanium Dioxide.** E. Belyakova, A. Komar and V. Mikhailov. (Metallurg, 1939, No. 4-5, pp. 23-25). (In Russian). This study was undertaken in connection with a general investigation of the behaviour of titaniferous ores in the blast-furnace. The deleterious effect of such ores is the increase in viscosity of the slags caused by the titanium dioxide. In the experiments the titanium dioxide was reduced

with hydrogen at 1200°, 1300°, 1400° and 1500° C. and with charcoal at 1100° to 1600° C. The products of the reduction were cooled under reducing conditions and examined by the Debye method. Reduction with hydrogen resulted in the formation of  $Ti_2O_3$  and of some  $TiO$  above 1500° C. Regarding the products of the reduction of titanium dioxide with carbon, it is concluded that they consist of solid solutions of  $TiC$  and  $TiO$ .

**British Standard Specification for Foamed Blast-Furnace Slag for Concrete Aggregate.** (British Standards Institution, No. 877-1939). This specification forms one of a series of specifications authorised by the former Public Works Industry Committee for aggregates for use in concrete, and it is based on the research into this material carried out by the Slag Tests Panel of the British Iron and Steel Federation. The specification is limited to foamed blast-furnace slag with a lime content not exceeding 50% by weight.

**The Properties of Hydraulic Blast-Furnace Slags.** G. Mussnug. (Archiv für das Eisenhüttenwesen, 1939, vol. 13, Nov., pp. 193-199). The author first describes a new and rapid method of testing basic blast-furnace slag which gives a good indication of its setting and hardness properties when used for cement manufacture. Using this test, he examined the influence of the blast-furnace process on the properties of the slag. From these experiments he found that the hardenability of a rapidly-cooled, highly-basic, blast-furnace slag is to a great extent dependent upon the temperature achieved during the reduction. The higher the temperature the greater is the hardness obtained. The ratio of the silica to the alumina contents of the slag also has a pronounced effect on its properties, for he found that an increase in the proportion of silica increased the compressive strength of prepared specimens which had been stored in water and decreased the amount of contraction.

**Present Position and Problems of Tar-Macadam Road Construction with Special Reference to Blast-Furnace Slags.** H. Lürer. (Stahl und Eisen, 1939, vol. 59, Oct. 5, pp. 1112-1115). The author discusses the specifications recently published in Germany which govern the quality of the tar and the grain size of the crushed blast-furnace slag to be used in the manufacture of tar-macadam for roads.

**Installation for the Recovery of Metallic Iron Contained in the Slag Produced by the Desulphurisation of Bessemer Iron with Sodium Carbonate.** A. Wager. (Revue Technique Luxembourgeoise, 1939, vol. 31, July-Aug., pp. 92-96). The author describes an auxiliary plant which has been developed at the Burbach works in Saarbrücken for the treatment of the slag formed after the desulphurisation of molten iron with soda ash. The molten slag is poured into a large water tank; this causes the slag and the iron to granulate. The mixed granules are then conveyed to a separating plant in which one stream of water carries them down an inclined channel against which a second stream of water is directed in such a way that the difference in the specific gravities



of the two materials causes them to separate out. At these works the production is about 2000 tons of iron per day with 30–35 tons of slag, from which about 10 tons of iron in granulated form are recovered. The plant has operated successfully for eighteen months.

**Plant for the Granulation of the Soda Slag and for the Separation of the Iron and Slag.** A. Wagener. (Stahl und Eisen, 1939, vol. 59, Aug. 31, pp. 990–992). An abridged German translation of the description of the slag-treatment plant at the Burbach works in Saarbrücken. (See preceding abstract).

**The Reduction of Silica and Alumina.** M. S. Maksimenko. (Metallurg, 1939, No. 4–5, pp. 27–34). (In Russian). The reduction of silica and alumina is considered from the point of view of the production of ferro-silicon and ferro-aluminium. The considerations include the thermo-chemical aspect of the reduction of silica and alumina with carbon and the effect of the presence of iron in the production of ferro-silicon and of the presence of silica and alumina simultaneously in the production of silico-aluminium. A theoretical treatment is given of the problem of the ratio of the size of the quartz to that of the coke pieces, and the preparation of the charge is dealt with. As regards the type of furnace for the production of silico-aluminium, the author concludes that the double-electrode single-phase type is to be preferred to the single-electrode single-phase furnace with a conducting hearth.

**Electrolytic Manganese, a New Metallurgical Raw Material.** W. L. Hammerquist. (Steel, 1939, vol. 105, Oct. 30, pp. 42–45). The author describes a process developed by the Electro Manganese Corporation by which 99.94% pure metallic manganese can be obtained on a commercial scale. In this process the ore is reduced in an electric furnace at a temperature of 600–700° C. by the action of a stream of producer gas. The product, which now consists mostly of manganous oxide, is leached with spent electrolyte containing ammonium sulphate, sulphuric acid and a small amount of manganous sulphate. The next stage is that of removing the impurities such as iron, arsenic, nickel, cobalt, molybdenum and phosphorus, after which the purified solution is electrolysed, using lead anodes and stainless-steel cathodes. The manganese is deposited on the cathodes, and after about 60 hr. immersion these are removed and dipped in a solution which prevents the manganese from oxidising in the atmosphere. The manganese plates are flaked off the stainless steel cathodes by flexing them in a special jig.

**The Rennerfelt-Kalling Process for the Dry-Refining of Granulated Pig Iron.** Bo Kalling and I. Rennerfelt. (Stahl und Eisen, 1939, vol. 59, Sept. 28, pp. 1077–1082). This is an abridged German translation of the account of the “R.K.” process of decarburising granulated pig iron which appeared in Jernkontorets Annaler, 1939, vol. 123, No. 3, pp. 115–154. (See Journ. I. and S.I., 1939, No. II., p. 137 p).

**Further Notes on Sponge Iron.** E. P. Barrett. (Steel, 1939, vol. 105, Oct. 30, pp. 48-52). The author discusses the results of investigations of the process of manufacturing sponge iron which have been undertaken by the U.S. Bureau of Mines. He describes a form of oil-fired rotary kiln capable of producing about 1 ton of sponge iron per day from a charge consisting of a mixture of finely-ground ore and coal in the proportion of five to three. The best results were obtained by working the kiln at a temperature of about 950° C.

**The Smelting of Low-Grade Acid Ores by the Krupp-Renn Process at the Essen-Borbeck Works of the Fried. Krupp Aktiengesellschaft.** H. Lehmkuhler. (Technische Mitteilungen Krupp, Forschungsberichte, 1939, vol. 2, Sept., No. 12, pp. 154-162). The author discusses the experience gained from four years' working of the Krupp-Renn process at the Borbeck Works of Friederich Krupp A.-G. He presents tables showing the analyses, grain sizes, composition of charge, and consumptions of ore and fuel relative to the reduction of low-grade German ores.

**The Krupp-Renn Process.** F. Johannsen. (Technische Mitteilungen Krupp, Forschungsberichte, 1939, vol. 2, Sept., No. 12, pp. 146-153). **The Present Position of the Krupp-Renn Process.** F. Johannsen. (Stahl und Eisen, 1939, vol. 59, Sept. 14, pp. 1041-1046). The author explains the principles of the Krupp-Renn direct process of ironmaking and some of its more recent developments. The plant and process have been previously described in Stahl und Eisen, 1934, vol. 54, Sept. 20, pp. 969-976 (see Journ. I. and S.I., 1934, No. II., p. 537). The process now has three applications. These are: (1) The production of pasty lumps of iron which are passed to the open-hearth or electric furnace for steelmaking; (2) the beneficiation of ores for the blast-furnace; and (3) the reduction of the ores of non-ferrous metals. The author discusses these three processes, giving tables of the analyses of the raw materials and products and other data.

**Classification of the Renn Direct Process under Materials, Power and Operating Conditions.** H. Bansen. (Technische Mitteilungen Krupp, Forschungsberichte, 1939, vol. 2, Sept., No. 12, pp. 139-145). The author explains the method of casting employed for the Krupp-Renn direct process of ironmaking. This article appeared previously in Stahl und Eisen, 1939, vol. 59, July 6, pp. 785-790. (See Journ. I. and S.I., 1939, No. II., p. 200 A).

**Heavy Industries of the German Reich.** (Iron and Coal Trades Review, 1939, vol. 139, Sept. 29, p. 438; Oct. 6, pp. 473, 475; Oct. 13, p. 504; Oct. 20, p. 542; Oct. 27, p. 578; Nov. 3, pp. 611-613). Continuation of a series of articles (see Journ. I. and S.I., 1939, No. II., p. 310 A). The discussion on the sources from which Germany hopes to maintain her imports of iron ore during the war is continued, and it is shown that the 5,500,000 tons which formerly came from Narvik will be cut off. It is ex-

pected that Russia will have very little ore available for export. The sources of supply of manganese ore, steel scrap, pyrites and purple ores are considered in detail. With regard to pig iron, it is shown that the favourable balance between imports and exports of 129,000 tons in 1936 was converted by 1938 into an unfavourable balance of 383,000 tons. The war has cut off 50% of Germany's sources of supply of pig iron, but this deficit is compensated for to some extent by Germany's acquisition of iron and steel industries in Czechoslovakia and Poland. It is noted that the Soviet blast-furnace output is insufficient for Russian requirements. From an examination of Germany's position regarding supplies of alloying elements, it is seen that, apart from nickel and chromite, neither Scandinavia nor the Balkans can supply Germany with the other needed alloying metals, such as molybdenum, tungsten and vanadium, and the prospects of making up the deficit in supplies resulting from the blockade are far from promising. From statistics of productive-capacity it can be concluded that the iron and steel industry of Germany is working at or even above the critical economic capacity, *i.e.*, a capacity for output which can be sustained for an indefinite period without additions to plant. As to rolled products, it is estimated that the effective capacity of the Greater German iron and steel industries is about 20,000,000 metric tons per annum, and there appears to be every likelihood of the deficiency between supply and demand becoming accentuated.

**Raw Materials and Germany's Iron and Steel Industry.** (Metallurgia, 1939, vol. 20, Oct., pp. 207-208). The production of iron ore in Germany and her imports are reviewed and related to the increased demand for pig iron and steel for both armament and ordinary industrial purposes.

**The Charcoal-Iron Industry.** H. G. Jones. (Journal of the Royal Society of Arts, 1939, vol. 88, Nov. 24, pp. 41-50). Using as his material some recently-found documents and letters written to the Royal Society of Arts between 1750 and 1800, the author traces the history of the attempts made in that period to discover a substitute for charcoal for the smelting of iron ore.

**The Story of Broken Hill Proprietary.** (Sands, Clays and Minerals, 1939, vol. 3, Autumn issue, pp. 282-287). A historical account of the development and a description of the present plant of the Broken Hill Proprietary Co., Ltd., of Newcastle, New South Wales, are presented. This company sprang from a syndicate formed in 1883 to mine silver; later, ironstone was sought for use as a flux in lead smelting and the deposits discovered near the Spencer Gulf in South Australia were eventually found to hold a vast quantity of hematite and manganese iron ore. Building of the present iron and steel works was commenced in 1914 and the works were officially opened in June, 1915.

## FOUNDRY PRACTICE

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(Continued from pp. 9 A-10 A)

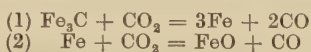
**Briquettes as a Substitute for Pig-Iron.** (Iron and Coal Trades Review, 1939, vol. 139, Nov. 10, p. 658). Some particulars are given concerning the use of compressed briquettes of cast-iron borings and turnings in the cupola. With modern machines, one of which is illustrated, briquettes can be produced with a density of at least 70% of that of pig iron, and the cost of production does not exceed 7s. per ton. The action of the briquette in the cupola is explained, and it is shown that the use of these briquettes results in a considerable reduction in the total-carbon content of the iron produced.

**Cupola Melting of Special Pig Irons.** C. D. Abell. (Foundry Trade Journal, 1939, vol. 61, Nov. 16, pp. 341-346). In these brief notes on the melting in the cupola of cold-blast and other special-quality irons, the author deals in particular with the effect of the temperature attained. He shows that the length of time the iron lies molten in the hearth is not of such great importance as the actual temperature which it reaches, for the higher the temperature the greater is the amount of cementite formed and the less is the amount of graphite precipitated upon cooling in the moulds. He concludes by pointing out that the process of annealing castings to obtain greater strength is only a substitute—and an expensive one—for controlled melting in the cupola.

**The Melting Technique, Structure and Mechanical Properties of Grey Cast Iron.** P. Bardenheuer. (Giesserei, 1939, vol. 26, Nov. 3, pp. 543-549; Nov. 17, pp. 564-566). The author discusses the relations between the conditions of solidification, the formation of the structure and the mechanical properties of grey cast iron. He points out the importance of the formation of a purely pearlitic matrix with very finely distributed graphite; and he suggests transferring the experiences gained in the production of steel to the production of cast iron and adjusting the melting process so that the quantity and distribution of the graphite deposited does not have a deleterious influence on the strength of the pearlitic matrix. In order to obtain a structure of the desired properties, undercooling during the solidification process has to be avoided, and various means to achieve this are reviewed. In particular additions to the melt which facilitate the formation of nuclei are considered in this connection. Suitable working conditions when melting in the cupola and in reverberatory and various types of electric furnaces are discussed at some length.



**The Cupola and the Melting of Iron.** L. F. Girardet. (Association Technique de Fonderie : Foundry Trade Journal, 1939, vol. 61, Nov. 2, pp. 299-300, 306). The author explains the reactions and movements of materials which occur in the following zones of a cupola : (1) The hearth up to the tuyere level ; (2) the oxidation zone, which extends from the tuyere level upwards for a distance equal to ten times the average diameter of the coke pieces ; (3) the reduction zone, extending from the top of the second zone to the concave layer where the temperature is about 1200° C. ; and (4) the preheating zone, extending from the reduction zone to the charging door. In studying the action of the ascending carbon dioxide on the descending hot and solid iron, the author explains that this is in accordance with the two equations :



The reaction (1) represents the gas reaction brought about with combined carbon instead of free carbon. The richness of the iron in elements which tend to expel the carbon (the so-called "graphitising elements") will favour refining, whilst "hardening elements" will hinder it. The two reactions develop on the surface of the pieces a less carburised and therefore less fusible skin ; the metal in the interior melts within this envelope as soon as the pieces reach the region where the temperature is sufficiently high. As the pieces descend to regions of higher temperature the decarburised skins melt and liberate their contents. It is thus seen that, contrary to the generally accepted theory, the pieces melt from the inside ; consequently the time taken by the pieces in descending through the preheating zone has an important bearing on the formation of decarburised iron.

**The Electric Furnace in the Grey Iron Foundry.** T. Klingenstein and H. Kopp. (Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns, 1939, vol. 7, Sept., pp. 147-156). In this discussion of the development of the use of the electric furnace for the manufacture of grey iron the authors draw attention to the following advantages which are apparent from experience gained at the works of Maschinenfabrik Esslingen : (1) A large proportion of poor-quality scrap can be charged, thus releasing better-class raw material for special purposes. (2) Turnings and light scrap previously unusable in a foundry can be successfully melted. (3) It is not essential to have a basic lining to the electric arc furnace, as it has been found that an acid lining can be used, and with the latter the sulphur content of the material charged is not so important. The authors also describe the plant at the Maschinenfabrik Esslingen, where there are two 2½-ton electric arc furnaces so arranged that they can be worked alternately from one transformer.

**Air-Furnace Melting for Blackheart Malleable Cast Iron.** H. G. Cochrane. (Engineering, 1939, vol. 148, Oct. 27, p. 484). The

author describes a reverberatory furnace and the melting process used in the manufacture of black heart malleable cast iron.

**Principles and Practice Involved in the Production of Steel Castings.** D. Clark. (Metals Treatment Society of Victoria: Australasian Engineer, 1939, vol. 39, Sept. 7, pp. 18-21, 39-40; Oct. 7, pp. 18-20). The author discusses the manufacture of steel castings in Australia under the following headings: (1) Steelmaking with (a) the electric furnace, and (b) the Tropenas converter; (2) moulding sand; (3) design, moulding and machining; (4) heat treatment; and (5) testing.

**Foundry Technique for Cast Iron in Theory and Practice.** J. Petin. (Giesserei, 1939, vol. 26, Oct. 6, pp. 497-505). The author develops formulæ for calculating the most suitable dimensions for gates and runners when preparing moulds for repetition castings, the object being to reduce as far as possible the weight of metal which remains in these after pouring. He also gives some examples of the application of these formulæ.

**American Moulding Without Boxes.** H. Allendorf. (Giesserei, 1939, vol. 26, Oct. 20, pp. 524-527). The author describes and illustrates the making of boxless moulds in American foundry practice and discusses the advantages and disadvantages of this technique.

**Recent Cleaning Appliances in the Campaign against Silicosis.** T. Geilenkirchen. (Giesserei, 1939, vol. 26, Oct. 20, pp. 517-524). The author reviews the development of the campaign to reduce the occurrence of silicosis in the foundry, and describes some of the improved types of casting-cleaning equipment in use in American and German foundries.

## PRODUCTION OF STEEL

(Continued from pp. 11 A-13 A)

**Metallurgical Investigations on the Working of the Basic-Bessemer Process with Oxygen-Enriched Blast.** W. Eilender and W. Roeser. (Stahl und Eisen, 1939, vol. 59, Sept. 21, pp. 1057-1067). The authors discuss the use of oxygen-enriched blast in the basic-Bessemer process on the basis of experience gained since 1930 at the Eisenwerkgesellschaft Maximilianshütte in Sulzbach-Rosenberg. At these works there are five 10-ton converters, and since 1938 90-95% of the charges have been blown with oxygen-enriched blast. The data presented cover the results obtained with blast containing up to 35% of oxygen. The authors show that a low-phosphorus iron (1.19-1.35% of phosphorus) can be blown without any difficulty with a blast containing 31% of oxygen. The most important advantages resulting from this process include a substantial reduction of the blast period for a given weight of charge and the increased proportion of scrap which can be used. The authors show, for instance, that with blast containing 28% of oxygen, the production in a given time can be increased by 16%, and with 35% of oxygen an increased production of 25% can be achieved.

**New Instructions for the Production of High-Grade Steel in Basic Open-Hearth Furnaces.** A. Khlebnikov. (Stal, 1939, No. 4-5, pp. 14-17). (In Russian). The working instructions given are the result of observations on a large number of heats in which a total of some 10,000 tons of high-grade carbon and low-alloy steel was produced. Brief particulars of the conditions existing at the plant at which the work was carried out are given. The brief instructions deal with the composition of the charge, the charging, the addition of lime, running off the slag, the boil (rate of carbon elimination), the oxidising slag and its properties, the addition of manganese, de-oxidation in the furnace and ladle, and teeming practice. Brief notes covering melting control tests are given.

**Some Changes in the Method of Firing and in the Repair of Open-Hearth Furnaces.** S. Sapiro. (Stal, 1939, No. 4-5, pp. 8-11). (In Russian). It is pointed out that the heating of open-hearth furnaces is limited by the resistance of the refractories, which are heated very nearly to their softening points. The author makes the suggestion of heating the furnace by means of two flames, one of which would be produced by burning gas of low calorific value (blast-furnace gas) in a layer in the vicinity of the roof, whilst the other would be produced by burning gas of high calorific value (coke-oven gas) in a layer above the bath. The two gases are made to move in layers, and are prevented from mixing by injecting them

through separate nozzles at different temperatures (one of the gases being supplied cold, depending on the sulphur content of the coke-oven gas) and pressures (1200–1600 and 30–40 mm. of water respectively). It is claimed that the above method possesses all the advantages of coke-oven-gas firing without any of its disadvantages. The author examines the burner design, the movement of the gases in the furnace and the thermal characteristics of the gas streams. The new method can also be applied to liquid-fuel-fired furnaces by supplying an upper stream of blast-furnace gas or, where this is not available, utilising the gaseous products of combustion from the exhaust ports. This method of firing will also enable minor repairs to various upper parts of the furnace to be made without stopping the furnace.

**Further Discussion of the Slagging Practice in Open-Hearth Melting.** Ya. Shneerov. (Stal, 1939, No. 4–5, pp. 12–14). (In Russian). The author criticises the formula given by L. P. Vladimirov for the melting time in terms of the weight of the charge and thickness of the slag layer in the open-hearth furnace (*see* Journ. I. and S.I., 1938, No. II., p. 210 A). This formula, it is pointed out, does not reflect practical results which demonstrate the increase in output with increased weight of charge. This is due to the exaggerated importance assigned to the thickness of the slag layer when considering heat transfer.

**Duration of the Boil in Basic Open-Hearth Melting and the Quality of the Steel Produced.** V. Mozharov. (Stal, 1939, No. 3, pp. 18–24). (In Russian). A discussion of certain aspects of open-hearth practice leads the author to suggestions designed mainly to improve the utilisation of the thermal capacity of the furnace. Qualitative indications should be used to fix the duration of the period of the active boil (before the addition of ore), rather than numerical data. The oxidation of the carbon should be rapid, with a correspondingly active boil, without any limitations regarding the rate of elimination of the carbon. The temperature of the bath should be raised to correspond with the rate of elimination of the carbon in such a way that the necessary temperature of the metal is reached. The above conditions are achieved by appropriate slagging practice, in particular by the control of the iron oxide and manganese contents and of the viscosity. The state of the metal bath is tested as regards temperature by pouring the metal from a test ladle on to a plate, and as regards cleanliness of the metal by casting a small test ingot which is then forged flat—if the boil is satisfactory the edges of the plate should be free from cracks. The charge should be melted at the highest possible temperature. Brief details of three heats in which the above practice was satisfactorily applied are given.

**Preventing the Loss of Manganese in the Open-Hearth Process.** P. Bardenheuer and G. Henke. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1939, vol. 21, No. 16, pp.



243-260). The authors present a detailed account of their investigations of methods of working the open-hearth furnace in the duplex process so as to reduce as much as possible the amount of manganese lost in the slag. The tests were carried out at the works of Hoesch A.-G. in Dortmund with one tilting and three fixed open-hearth furnaces of 100 tons capacity. In the ordinary method of working it was observed that the molten metal charged contained slag-formers, mainly phosphorus pentoxide and silica, which necessitated large additions of lime, and this resulted in a large proportion of slag being formed and a large proportion of the manganese being lost. The measures adopted to reduce the amount of slag and to assist the return of the manganese from the slag into the steel included: (1) The use of runners lined with a tar-dolomite mixture instead of sand when transferring the open-hearth iron from the ladle to the steel furnace; (2) working the furnace with a high carbon concentration and taking care not to produce a highly basic slag; and (3) the adoption of a special method of teeming when tapping the finished steel. This consisted of holding the ladle in an almost horizontal position against the runner from the tap-hole and gradually bringing the ladle to the vertical position as it filled. This prevented the metal from falling vertically into the ladle, and there was therefore no turbulence. The amount of manganese lost was reduced by 25-33% by adopting this pouring technique, and this resulted in a saving of 50% in the ferro-manganese additions. The authors present tables giving full particulars of the weights and analyses of the materials charged, the slags and the steel produced, from which an accurate picture of the new method of working the Hoesch process to produce manganese steel can be obtained.

**"Tailor-Made" Steels.** T. Grey-Davies. (Sheet Metal Industries, 1939, vol. 13, Sept., pp. 1115-1117; Nov., pp. 1331-1333). Continuation of a series of articles (*see* Journ. I. and S.I., 1939, No. II., p. 203 A). In Part XII. the author discusses the deoxidation of steel in the open-hearth furnace, explaining how this process is controlled by correlating the iron-oxide content of the slag with the analysis of the steel. He also deals with the effect of aluminium additions on the formation of blow-holes in the core of the ingot and of cracks in the surface. He concludes this part with brief references to the Fitterer pyrometer and the Schofield quick-immersion pyrometer for taking steel bath temperatures. The author devotes Part XIII. to describing the technique of direct-pouring and bottom-pouring steel into ingot moulds, and he then relates failures which occur in pressing and other finishing operations to segregation, to the presence of non-metallic inclusions and to other phenomena which occur at the ingot stage of production.

**The Electric Arc as the Source of Heat for Electric Furnaces.** H. Siegel. (Stahl und Eisen, 1939, vol. 59, Nov 23, pp. 1261-1267). From observations made during the operation of electric furnaces

for steelmaking the author analyses the conditions under which a quiet and uniform arc can be maintained. He finds that the relationship of the current to the voltage must be most carefully controlled to achieve this. The choke is not so important for the maintenance of a steady arc as is generally believed.

**Electric Furnaces for the Melting of Metals.** G. R. Bashforth. (Staffordshire Iron and Steel Institute: Iron and Coal Trades Review, 1939, vol. 139, Nov. 10, pp. 657-658; Nov. 17, pp. 694-695). The author briefly describes the early Stassano, Héroult, Girod, Nathusius, Kjellin and Röchling-Rodenhauser electric furnaces. He points out some changes in electric-furnace design which have been found to be necessary on increasing their capacity. He also describes the principles of the high-frequency induction furnace, and in conclusion gives some particulars of electric furnaces which are extensively used in Scandinavia and Italy for the reduction of iron ores; in these furnaces no blast is applied and the coke is not used to supply heat, but as a reducing agent only.

**Alloy Steels.** G. B. Waterhouse. (Eighth Perin Memorial Lecture: Tisco Review, 1939, vol. 7, Sept., pp. 648-654). The author reviews the history of the development of the manufacture of manganese, silicon, nickel, nickel-chromium, and tungsten steels and gives a brief account of the sintering of powdered alloying elements to make alloys which cannot be manufactured by ordinary steelmaking processes.

**The Recovery of Slag High in Vanadium from the Basic-Bessemer Converter and its Use in the Electric-Arc Furnace.** A. Harr. (Stahl und Eisen, 1939, vol. 59, Oct. 19, pp. 1145-1154; Oct. 26, pp. 1174-1178). The author reports on some investigations at the Dortmund Works of Hoesch Aktiengesellschaft of the process that this company has developed for the recovery and utilisation of the vanadium present in German iron ores. The average vanadium content of German pig iron for the basic Bessemer process is about 0.12%, so that on this basis, with a production of 10.7 million tons of basic iron in 1937, the quantity of vanadium passing to the converters amounted to 12,840 tons. The process developed for the recovery of vanadium for the manufacture of vanadium-bearing steel is carried out in several stages. The first consists of manufacturing a vanadium-rich pig iron using a specially prepared charge comprising sintered ores, slags from the mixers and ladles, and waste and spillage from the Bessemer converters. This stage of the process produces iron containing about 1% of vanadium with high phosphorus and manganese. The next stage consists of blowing this iron in a Bessemer converter and slagging off the vanadium; the remaining iron is put into the mixer for the manufacture of ordinary basic steel. The final stage of the process is that in which the vanadium-rich slag (11-12% of vanadium) is added to the charge in an electric-arc furnace in order to produce steel containing about 0.11% of vanadium. In this final stage a finely-ground

mixture of the vanadium-rich slag with carbon and silicon as deoxidisers is thrown on to the melt immediately after the ferromanganese has been added. The author includes tables of analyses of the pig iron, slags and steel at various stages of the process and also discusses the costs.

**Cooling Conditions in Ingot Moulds.** I. Ya. Granat and A. A. Bezdenzhnykh. (Foundry Trade Journal, 1939, vol. 61, Nov. 16, pp. 335-336). An abridged English translation is presented of an article which appeared in *Metallurg*, 1938, No. 10, pp. 19-33, in which the authors studied the effect of the mould-wall thickness on the structure of steel ingots. (See Journ. I. and S.I., 1939, No. II., p. 17 A).

**The Influence of Mould Design on the Quality of Bottom-Poured Ingots.** P. V. Umrikhin and A. L. Bogorosdkiy. (*Metallurg*, 1939, No. 6, pp. 18-29). (In Russian). The first part of the paper deals with the effect of the quality, temperature and rate of pouring of the steel and the mould temperature on the quality of the ingots, particularly with regard to piping, cavities and porosity. In the experiments particular attention was given to the conditions under which the ingot cooled; these were investigated by means of temperature measurements, using thermocouples inserted into the mould wall at various points. The existing mould design was found to be unsatisfactory from the point of view of heat flow. The unsatisfactory features were: (a) Excessive wall thickness of the hot-top portion, as well as of the main part of the mould; and (b) too small a volume of the ingot head and the tapering of the mould towards the top. The above drawbacks were rectified in two new mould designs. Tests of these moulds are described with reference to the structures of the ingots obtained. Thin walls to give improved heat removal, larger volume of head for better feeding, and absence of taper, which gives a better ingot surface, are the special features of the new moulds.

**A Contribution to the Question of the Solidification of Steel Ingots.** R. Hohage and R. Schäfer. (*Archiv für das Eisenhüttenwesen*, 1939, vol. 13, Sept., pp. 123-125). It had been observed, contrary to expectation, that a chromium-nickel steel ingot, which evidently contained hydrogen, had a particularly coarse primary structure and showed marked columnar crystallisation. This evidence had led to the conclusion that although a high hydrogen content did not produce any rimming action, it did have some effect upon the process of solidification. In order to investigate this phenomenon, the authors examined the structures of a number of 20-kg. chromium-nickel steel ingots of analyses within the range chromium 0.65-2.54% and nickel 0-3.8% cast in water-cooled copper moulds. They compared the structures of ingots prepared and cast under a low vacuum with those of identical analysis prepared and cast under normal conditions. It was found in every case that the vacuum-melted and cast ingots had a fine-grained structure with



no columnar crystals, whilst the open-cast ingots had a coarse-grained structure with columnar crystallisation. From these observations the authors came to the general conclusion that two conditions are essential to produce columnar crystallisation, namely, a high rate of heat transfer and a given gas content; either condition by itself is not sufficient.

**Inverse Segregation Phenomena in the Upper Part of an Ingot.** I. Braynin and P. Oksyuzov. (Stal, 1939, No. 3, pp. 48-52). (In Russian). As a result of investigations of sections through medium-carbon steel by means of Baumann prints, microscopical examination and carbon, sulphur and phosphorus determinations, the authors were led to the conclusion that the inverse segregation in the upper part of an ingot develops in the process of the solidification of the metal in the region of the shrinkage cavity as a result of the residual melt being sucked downwards. The depth of the inverse-segregation zone depends on the size and shape of the ingot. The spots of inverse segregation depend, other conditions being equal, on the duration of the solidification of the residual melt, and consequently on the carbon content of the steel; the inverse segregation increases with an increase in the carbon content. A zone of direct segregation is situated below the region of inverse segregation.

**Experience in the Melting and Rolling of SDS Steel.** S. Belorussov. (Stal, 1939, No. 3, pp. 24-35). (In Russian). The composition of SDS steel is carbon 0.12-0.18%, manganese 0.7-1.0%, silicon 0.25-0.40%, sulphur 0.04%, phosphorus 0.04%, chromium 0.4-0.6%, copper 0.5-0.7%. Certain aspects of the melting, teeming, preheating and rolling of this steel are dealt with in the light of practical experience. Particular reference is made to ingot defects in relation to different casting methods and the subsequent cooling of the ingots. The superiority of bottom-pouring into hot-topped moulds is noted. For slabbing, ingots were preheated to, on the average, 1180° C., and the temperature at the end of the rolling period was about 980° C. To obtain maximum mechanical properties hot-rolled sheets should be made to develop the ageing effect, for which purpose they have to be cooled slowly through the range 400-450° C. This can be achieved by special stacking of the hot sheets after straightening or by a separate heat treatment.

**Carbide Heterogeneity of Ball-Bearing Steel and Means of Removing it.** V. P. Remin. (Metallurg, 1939, No. 4-5, pp. 57-63). (In Russian). Carbide segregation in ingots from a number of differently treated heats and the effect of rolling on this phenomenon were examined. Carbide segregation in ingots appeared to be due to the incomplete dispersion of carbide-forming additions in the melt. It can be observed in samples taken from the ladle, and is therefore independent of the rate of solidification. The carbide fibre encountered in rolled products can be eliminated by a heat treatment designed to disperse the carbides by diffusion.



## REHEATING FURNACES

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**New Soaking Pits at Atlantic Steel Co.** (Industrial Heating, 1939, vol. 6, Aug., pp. 723-724). A brief illustrated description is given of five new circular soaking pits installed at the works of the Atlantic Steel Co. These soaking pits are heated with natural gas, and the gas-air ratio and the gas pressure are automatically controlled by Hagan control instruments.

**Steel Plant Furnaces—Section 3. Furnaces for Pipe and Tubes : Parts I. and II.** M. H. Mawhinney. (Industrial Heating, 1939, vol. 6, July, pp. 608-612; Sept., pp. 806-810). In the first part of Section 3 of this series of articles on the furnaces used in steel-works for the manufacture of pipes and tubes the author describes continuous and batch furnaces for heating skelp prior to bending it into cylindrical form, and the welding furnace in which it is reheated ready for butt-, lap- or hammer-welding. In the second part he deals with the furnaces used in conjunction with Mannesmann and pilger tube mills.

**The Conversion of Forging Furnaces from Oil-Firing to Long-Distance Gas.** W. G. Rathmann. (Stahl und Eisen, 1939, vol. 59, Nov. 2, pp. 1205-1209). The author compares the operating data for a number of furnaces for forgings now fired by long-distance gas with the data for the same furnaces before their conversion from oil-firing. He shows that with the new fuel the throughput of the furnace per hour can be slightly increased, and, with the use of coal-tar pitch as a carburetting medium, a small reduction in fuel costs can be achieved.

**An Improved Burner for Slot Furnaces.** M. W. Martin and N. B. Lantz. (Metal Progress, 1939, vol. 36, Sept., pp. 243-246). The authors describe and illustrate a special design of burner for heating small bars for forging purposes. With this burner a combination of oil, natural gas and air forms the fuel.

## FORGING, STAMPING AND DRAWING

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(Continued from pp. 14 A-16 A)

**Shell Forging by the Progressive Deep Piercing Process.** (Machinery, 1939, vol. 55, Nov. 16, pp. 171-172). An illustrated description is given of a process used in some American arsenals for the production of 2-in. shells from 1-in.-dia. bar in a progressive deep-piercing machine which completes the operation in seven strokes of the press. The machine operates at 28 strokes per min., and no reheating is necessary between the stages of forming. The finished forging is very clean and the inside requires no machining. The external surface is given a light skimming cut and the ends require facing to the required length.

**Forged Rolls for Cold-Rolling and Their Production.** R. Scherer. (Stahl und Eisen, 1939, vol. 59, Oct. 5, pp. 1105-1111). The author discusses the design, manufacture, heat treatment and grinding of forged steel rolls for two-high cold-rolling mills.

**Tools for Deep-Drawing and Pressing.** J. D. Jevons. (Metal Industry, 1939, vol. 55, Nov. 17, pp. 425-428; Nov. 24, pp. 449-451). Continuing this series (*see* p. 15 A), the author stresses the necessity of close co-operation between the tool designer and the heat-treatment department and describes in detail the various stages of heat treatment for tools and dies for drawing and pressing. He stresses the importance of packing tools in charcoal before the heat treatment or taking some other precaution to prevent decarburisation.

**Modern Wire Drawing Practice.** J. J. Phifer. (Iron and Steel Engineer, 1939, vol. 16, Oct., pp. 26-30). The author describes some of the recent types of wire-drawing machines used in America for the drawing of low-carbon steel wire from hot-rolled rods with either intermittent or continuous drawing blocks.

**Some Features of the Wire Industry.** W. Breunning. (Metals Treatment Society of New South Wales, July, 1939: Australasian Engineer, 1939, vol. 39, Sept. 7, pp. 12-14, 47-49). The author describes the plant and processes used by Lysaght Brothers and Co., Proprietary, Ltd., at their works on the Parramatta River, Australia.

## ROLLING-MILL PRACTICE

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(Continued from pp. 17 A-18 A)

**Modern Engineering as it Affects Rolling-Mill Practice and Design.** E. T. Judge. (Proceedings of the Cleveland Institution of Engineers, 1938-1939, No. 5, pp. 183-200). With a view to spreading knowledge of recent improvements in practice and design which have taken place in separate branches of the rolling-mill industry, the author in this paper discusses these improvements not under headings of types of mills but under the headings: Rolling, Finishing and Services. Under "Rolling" he pays particular attention to the advantages of using water-lubricated synthetic-resin bearings, quoting some figures of increased life and saving in power consumption which have been achieved in practice. In the section on "Finishing" he discusses in particular the use of continuous cooling banks for heavy sections. In conclusion, under "Services," he considers questions of power supply, high-pressure oil lubrication systems and roll maintenance.

**Rolling Flat Wire.** (Iron Age, 1939, vol. 144, Nov. 9, pp. 38-43). An abridged English translation is presented of the paper by A. Pomp, H. Höhle and W. Lueg in which they considered the effect of different rolling conditions on the spread of the metal when round wire is rolled flat. This paper appeared previously in *Stahl und Eisen*, 1938, vol. 58, Sept. 1, pp. 937-943 (*see* Journ. I. and S.I., 1938, No. II., p. 356 A).

**The Influence of External Friction and Tension on the Pressure of the Metal on the Rolls in Rolling.** A. I. Tselikov. (Metallurg, 1939, No. 6, pp. 61-76). (In Russian). The main part of the article is devoted to deriving an expression for the distribution of pressure on the area of contact between the metal and the rolls. Integration of the expression for the specific pressure leads to a formula for the total pressure on the rolls. Consideration is also given to the effect of tension externally applied to the strip on either the input or output side or both, as well as to the determination of the critical width of the rolling gap. In conclusion the results calculated from the various expressions are compared with experimental data published by Skefko, a good agreement between the two being observed.

**Investigation of the Methods of Costing and Increasing the Efficiency of a Roll-Turning Shop.** E. Nowak and H. Stevens. (Archiv für das Eisenhüttenwesen, 1939, vol. 13, Nov., pp. 231-240). The authors describe a time study of the operations involved in roll-turning and five different methods of presenting the data obtained.

**Output Capacity of a Blooming Mill.** M. Zaroshchinskiy. (Stal, 1939, No. 3, pp. 36-44). (In Russian). Detailed formulæ are developed for the output capacity of a blooming mill based on the time of passage of the metal through the rolls, the acceleration and deceleration periods and the period of constant speed of rotation of the rolls being considered both independently and in relation to the power of the driving motor. These, plus the intervals between the passes, give the total rolling time. The outputs of a blooming mill when rolling down ingots of different sizes to  $250 \times 250$  mm. and  $300 \times 300$  mm. blooms are worked out and some reference is made to the next stages of the rolling of the  $300 \times 300$  mm. blooms in a continuous mill.

**New Continuous Strip Mill.** E. F. Ross. (Steel, 1939, vol. 105, Oct. 16, pp. 56-60; Oct. 23, pp. 56-60). The author describes and illustrates the important improvements which have been carried out at the Indiana Harbor Works of the Youngstown Sheet and Tube Co. The reconstruction involved the installation of a 54-in. continuous hot strip mill, the rebuilding of the 35-in. blooming mill to a 46-in. unit, and the construction of a new 165-ton open-hearth furnace.

**The Continuous Wide Strip Rolling Mill.** E. D. Martin. (Mining and Metallurgy, 1939, vol. 20, Oct., pp. 453-457). The author traces the development of the continuous rolling of wide strip in America and considers the effects which the introduction of this process has had on wages, salaries, profits and the purchasing public.

**Courtybella Works of the Whitehead Iron and Steel Company, Limited, Newport, Mon.** (Iron and Coal Trades Review, 1939, vol. 139, Nov. 17, pp. 681-687). A detailed description with numerous illustrations is presented of the Courtybella Works of the Whitehead Iron and Steel Co., Ltd., in South Wales. This company was the first to adopt and develop the continuous rolling process. (Seep. 17 A).

**"Back-Pull" Patent Issued.** (Wire and Wire Products, 1939, vol. 14, Nov., pp. 647-648, 666-667). A complete list is given of the claims allowed by the United States Patent Office in the patent filed respecting the Smith-Stringfellow process of applying back-pull in the rolling of steel strip.

**Cold-Rolling—A Heat Problem.** G. Reimer. (Stahl und Eisen, 1939, vol. 59, Oct. 12, pp. 1134-1136). The author presents a mathematical study of the thermal-conductivity problems which arise in connection with the cooling of rolls used for cold-rolling, and shows how these problems influence roll design.

**Backing Rolls for Cold-Rolling Mills.** R. Hohage. (Stahl und Eisen, 1939, vol. 59, Nov. 2, pp. 1197-1200). The author reviews the design and manufacture of backing rolls for cold-rolling mills with special reference to the chemical composition and properties of cast, forged and composite rolls. Composite rolls are those with a forged-steel centre on to which a hardened cast-steel shell is shrunk.



## HEAT TREATMENT

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(Continued from pp. 19 A-24 A)

**A Contribution on the Heat Treatment of Cast Iron.** O. Glaser. (Giesserei, 1939, vol. 26, Sept. 8, pp. 466-467). The author describes a form of heat treatment which was found suitable for small cast-iron pistons for a rotary compressor. The iron had the following analysis: Carbon 3.1-3.3%, silicon 1.8-2.4%, manganese 0.5%, phosphorus 0.6-0.8% and sulphur 0.1%. After annealing and machining, the pistons were heated to 850° C. and quenched in oil. They were then aged for several hours in oil.

**Small Parts Carburized in Melted Salt.** H. H. Whittingham. (Metal Progress, 1939, vol. 36, Sept., pp. 264-266). The author describes a technique for the carburising of small parts which causes very little distortion. This treatment consists of carburising in a cyanide bath at 1650° F., transferring the parts to a second bath of similar salt at 1450° F. and finally quenching in oil.

**Salt-Bath Treatment in "Carboneutral."** (Wire Industry, 1939, vol. 6, Oct., pp. 655-656). A brief description is given of an electrically heated salt-bath furnace for hardening high-speed steel tools. The salt bath in this furnace is composed of "Carboneutral," a patented material which does not decarburise the steel. The furnace comprises a pot or crucible of selected refractory material with electrodes recessed in evenly-spaced, vertical slots in its sides; the molten "Carboneutral" is heated by the passage of the current through it.

**Flame Hardening of Cast Iron.** F. G. Sefing. (Iron Age, 1939, vol. 144, Oct. 19, pp. 43-49). The author discusses suitable types of cast iron for manufacturing the ways of lathe beds with special reference to their flame-hardening properties. He reports on some experiments undertaken to determine the effect of additions of nickel and of nickel and chromium on the depth and degree of hardness obtainable.

**Accelerated Methods of Nitriding Tool Steels and Nitralloy 35KhMYuA.** N. N. Lipchin and I. K. Glazyuk. (Metallurg, 1939, No. 6, pp. 47-53). (In Russian). Nitriding tests under laboratory and works conditions on quenched and tempered chromium-tungsten-vanadium, chromium-molybdenum, chromium-tungsten and chromium-vanadium tool steels and nitralloy 35KhMYuA (carbon 0.31%, silicon 0.21%, manganese 0.42%, aluminium 1.38%, chromium 1.64%, molybdenum 0.73%) are described. Hardness tests showed that satisfactory cases could

be obtained. The three-stage nitriding at 500–600° C. shortened the nitriding time by about 60%, as compared with nitriding at 480–500° C. for the same depth of case. Aniline or pyridine as catalysts were about equally effective in the three-stage process. Nitriding at 650° C. gave only a thick case, but with reduced surface hardness. This may be suitable for not very highly stressed tools used at elevated temperatures. Machining tests with nitrided tools demonstrated their superior stability, except when high loading occasionally resulted in the breaking away of the case at the tool tips. Nitriding of pressure-die-casting dies prolonged their life and prevented brass or Silumin from sticking to them. Nitriding also eliminated the need for quenching and tempering the dies and the attendant possibility of deformations and increased cost.

**The Nitriding of Austenitic Steels.** G. F. Kosolapov. (Metallurg, 1939, No. 6, pp. 54–60). (In Russian). The object of the investigation was to determine: (1) The increase in hardness after nitriding of a number of high-alloy chromium-nickel, chromium-manganese-tungsten, chromium-nickel-manganese and chromium-tungsten austenitic steels, (2) the influence of the nitriding temperature on the depth and hardness of the case, and (3) the nature of the structural changes which occur in the nitrided layer. These changes were studied primarily by X-ray methods supplemented by metallographic examination. The tests showed that the nitriding of steels containing appreciable amounts of chromium or manganese gave a hardness equal to that of the quenched steel. Steel containing 36% of nickel underwent practically no increase in hardness. Nickel steels containing an appreciable amount of chromium or manganese also showed appreciable increases in hardness. In several instances the temperature was found to have a pronounced effect on the results obtained in nitriding. The nitriding temperature for maximum hardness is higher for austenitic steels than for  $\alpha$ -phase steels. In view of the similarity of the X-ray characteristics of the various nitrides the formation of which might have been expected, no attempt was made to distinguish between nitrides of similar crystal structure. The diffusion of nitrogen into austenitic steels is much slower than into  $\alpha$ -phase steels. In the majority of austenitic steels the  $\gamma$ -phase is not retained in the nitrided layer, but decomposes into the  $\alpha$ -phase and nitrides. This may be accompanied by a reduction in the corrosion resistance. Lattice distortion and the precipitation of dispersed nitrides are to an equal extent responsible for the hardening.

**Modern Gas-Fired Furnaces.** A. G. Robiette. (Metal Industry, 1939, vol. 55, Oct. 27, pp. 365–368). The author surveys the trends of recent progress in the field of gas-fired heat-treatment furnaces. The survey shows that the increased efficiency and flexibility of gas-fired equipment render it suitable for applications previously only possible for electric furnaces.

**Automatic Control of Gas-Fired Wire Heat Treatment Furnaces.**

O. G. Pameley-Evans. (Metallurgia, 1939, vol. 20, Oct., pp. 217-218). The author points out and discusses some of the details to be borne in mind by furnace engineers and operators who use automatically controlled plant. The discussion is confined to the control of batch and continuous gas-fired furnaces.

**Double-Lead Patenting.** (Steel, 1939, vol. 105, Oct. 30, pp. 56-58). A brief description is given of the patenting equipment of an American wire manufacturer with which wire for such purposes as musical instruments and aircraft construction is heat-treated. The interesting features of this plant are the two lead kettles; both are heated with producer gas. The first is the hardening kettle and the second is the quenching kettle, and they are kept at temperatures of about 1625° and 1000° F., respectively. The surface of the molten lead is kept covered with fine anthracite to prevent oxidation.

**Accelerated Annealing for the Production of Granular Pearlite in Cold-Rolled Strip.** N. T. Gudtsov, N. F. Vyaznikov and M. I. Poysikhis. (Metallurg, 1939, No. 4-5, pp. 63-75). (In Russian). It is desirable to obtain granular pearlite in the intermediate annealing of cold-rolled strip, as this structure corresponds to the maximum ductility of the metal. The experimental work was done on plain carbon steel strip containing carbon 1.04%, manganese 0.25%, silicon 0.37%, sulphur 0.017%, phosphorus 0.010%, and a silicon steel with carbon 0.67%, manganese 0.65%, silicon 1.45%, sulphur 0.016%, phosphorus 0.007% and chromium 0.37%. After determination of the critical points the effect of subjecting both steels to the following heat treatments was investigated: (a) Stepped quenching (in lead bath from 800-900° C. to 275-375° C. for 20 sec., followed by air-cooling and tempering at 650-700° C. for 15-120 min.). In some experiments with the silicon steel the lead-bath quenching was replaced by air quenching from higher temperatures; (b) normalising followed by high-temperature tempering; (c) supercooling of the austenite by quenching in a lead bath followed by short-period isothermal transformation at a higher temperature and finally high-temperature tempering (spheroidising); (d) short-period austempering, followed by spheroidising; (e) ordinary annealing with subsequent spheroidising; and (f) repeated annealing (alternate heating to 650-700° C. and cooling) below the A<sub>1</sub> point. With the cold-rolled carbon-steel strip the best results were obtained by method (d). The steel thus treated had a tensile strength of not more than 65 kg. per sq. mm. and an elongation of not less than 20%. The best treatment for the silicon steel was that of holding at 850° C. for 15 min., quenching to 500° C. and holding for 2 min., followed by spheroidising at 710° C. for 1 hr. In this case the steel had a tensile strength of 77 kg. per sq. mm. and an elongation of 17%. The possibility of applying the above treatments to the strip by a continuous process is mentioned.

## WELDING AND CUTTING

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(Continued from pp. 19 A-24 A)

**New Knowledge Concerning the Welding Characteristics of Welding Machines.** W. Scheuring and K. Haas. (Elektroschweissung, 1939, vol. 10, Oct., pp. 185-192). The authors develop a means of testing the welding characteristics of D.C. welding generators and demonstrate how it can be used to assess in a simple manner the properties of a generator without actually doing any welding. The gradient of the voltage-amperage curve is the basis of the assessment.

**Multiple Spot Welding.** (Steel, 1939, vol. 105, Oct. 16, pp. 63-66, 98). A description is given of a machine which was developed to produce spot welds in sheets of 18/8 stainless steel 0.025 in. thick in the manufacture of evaporator chambers for refrigerators. This machine is a multiple spot welder with six separate heads, each with its own transformer. A very high pressure is exerted on the welding tips by automatic hydraulic mechanism and the welding time is very short.

**Tin-Coated Electrodes.** A. R. Eckberg. (Steel, 1939, vol. 105, Oct. 23, pp. 52-53, 74). The author describes an improved method of welding employed in the manufacture of air ducts for air-conditioning plant. It had been found that in the welding of galvanised sheet with a carbon electrode and a copper-silicon filler rod a narrow strip of steel unprotected by either zinc or copper was left adjacent to the weld. In the method described a welding rod of a copper alloy coated with tin is used, and when the correct technique is employed the tin covers the area formerly left bare.

**Tests with New Types of Welding Rods for Autogenous Welding.** C. Stieler. (Autogene Metallbearbeitung, 1939, vol. 32, Oct. 15, pp. 297-307). In this review of the results of tests of welds made with many new types of welding rods now obtainable in Germany, the author shows that oxy-acetylene welded joints of very high impact strength can now be produced without employing any special technique or heat treatment. He finds that in some cases the welds are rather hard or coarse-grained, but this has had no serious effect on their stability.

**Observations on the Arc Welding and Gas Cutting of High-Tensile Low-Alloy Structural Steels.** T. B. Wilkinson and H. O'Neill. (Proceedings of the Institution of Mechanical Engineers, 1939, vol. 141, Oct., pp. 497-511). High-tensile structural steels generally contain relatively small additions of alloying elements which affect their welding properties because of hardening effects. The authors present data regarding the composition and test values of some typical high-tensile steels, together with results on metallic arc-



welded joints. They describe laboratory cracking tests to determine the weldability of this high-tensile steel plate. The composition and inherent grain size of the steel, together with the conditions of welding, affect the properties of the heat-transformed zone. The authors find it is desirable to limit the carbon content to 0.20%, and, for single-run fillets, to use the relatively slow welding speed of 4-6 in. per min. with a fillet size of not less than half the thickness of the plate. They study the properties of various covered electrodes and report on some carburisation experiments which reveal interesting differences between electrodes. They also consider the cutting of these low-alloy steels with the oxy-acetylene torch and the hardness of the edge left by the flame.

**The Design of Welded Frames for Motor Lorries and Motor Lorry Trailers.** H. Schnedler. (*Autogene Metallbearbeitung*, 1939, vol. 32, Oct. 1, pp. 285-292). The author explains with numerous diagrams the forms of design most suitable for the welded steel frames of heavy motor lorries and trailers.

**The Torsional Fatigue Strength of Fillet Welds.** A. Thum and A. Erker. (*Elektroschweissung*, 1939, vol. 10, Nov., pp. 205-209). The authors report on an investigation of the torsional fatigue strength of steel assemblies which had been welded circumferentially.

**The Fatigue Strength of Welded Joints.** H. Blumberg. (*Autogene Metallbearbeitung*, 1939, vol. 32, Aug. 15, pp. 249-253). The author reviews the literature on the investigation of the fatigue strength of different forms of welded joints in steel plate.

**Properties of Brazed 12% Chrome Steel.** F. C. Kelley. (*Iron Age*, 1939, vol. 144, Nov. 2, pp. 33-35; Nov. 9, pp. 34-35). The author describes a technique which has been developed for the brazing of stainless steel. For testing joints made by this process the author used specimens of steel bar containing carbon 0.09%, chromium 12.0%, nickel 0.35%, manganese 0.50% and silicon 0.30%. The ends of two short lengths of the bar were ground flat and the two pieces were wired together with a 0.002-in. sheet of brazing metal in between. This assembly was placed upright in a flat boat and pushed into a tube provided with an inlet tube for pure hydrogen. The tube forming the housing was closed with a thin sheet of iron provided with a small hole to permit the hydrogen to escape. The whole assembly was pushed into the cooling zone of a furnace and the hydrogen supply turned on, after which the assembly was pushed into the heating zone and brought up to about 1200° C. in 20 min. A number of joints were made in this way in order to test three kinds of brazing metal; these consisted of: (1) Pure copper, (2) copper 85%, nickel 10%, iron 5%, and (3) copper 97%, cobalt 3%. The author also presents the results of numerous tensile and impact tests on the brazed pieces. In general, brazing metal of composition (2) produced the best results, tensile strengths of up to 139,600 lb. per sq. in. being obtained.

## MACHINING

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**An Analysis of Machinability Data from Cold Finished and Heat-Treated S.A.E. 1045 Steel.** O. W. Boston and W. W. Gilbert. (American Society for Metals, Oct., 1939, Preprint No. 10). The authors report on the results of machinability tests on six specimens of S.A.E. 1045 steel which were prepared by different forms of heat treatment. The tests were made to determine the cutting temperatures, the cutting forces, the quality of the surface obtained, and the relation between the cutting speed and the life of the tool.

**The Effect of the Surface Condition on some Components of Precision Machines.** L. Seletsky. (Schweizer Archiv für angewandte Wissenschaft und Technik, 1939, vol. 5, Sept., pp. 267-272). The author describes some methods of grinding, lapping and scraping for the production of smooth surfaces for precision machines for which a high degree of accuracy is demanded. He also explains and illustrates some optical methods of testing finished surfaces.

**A Discussion of Leaded Steels.** F. J. Robbins and G. R. Caskey. (American Society for Metals, Oct., 1939, Preprint No. 11). The authors describe an investigation of the mechanical properties and machinability of a number of lead-bearing steels. The results of the machinability tests are presented in the form of a chart in which the performance of each grade of lead-bearing steel is directly compared with a similar standard grade containing no lead. Suggestions as to the best rates of feed and cutting speeds are also made.

**A Survey of the More Recently Developed Cutting Materials.** H. W. Pinder. (Wild-Barfield Heat-Treatment Journal, 1939, vol. 3, June, pp. 53-58; Sept., pp. 66-70). The author describes the preparation and properties of the less orthodox cutting tools under the headings of high-speed steels, cast and cemented cutting alloys and dispersion-hardening alloys. In the second category he includes "Cutanit," a compound containing carbides of tungsten, molybdenum and titanium bonded by cobalt, as well as "Ardoloy," "Wimet" and "Ramet." "Ramet" is a tantalum carbide tool in which nickel has been substituted for cobalt as the carbide-cementing matrix. The dispersion-hardening alloy, the properties of which he describes, is known in America as Alloy 548; it is an alloy of iron, cobalt and tungsten and contains no carbon; in any except the quenched and tempered condition, it is comparatively soft. In conclusion the author discusses the practical applications of the various alloys which he has described.

**Polishing Technique for Stainless Steels.** W. M. Mitchell. (Iron Age, 1939, vol. 144, Oct. 19, pp. 56-59, 92-94; Oct. 26, pp. 32-35, 92). In the first part of his paper the author reviews the various types of stainless steels, the range of commercial finishes, the types of abrasives used for polishing, the preparation of the polishing wheel surfaces and the proper sequence of operations.

## PROPERTIES AND TESTS

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(Continued from pp. 37 A-46 A)

**The Relationships between the Elongation on Fracture and the Reduction of Area of Specimens with Diameter/Length Ratios of 1 : 5 and 1 : 10.** A. Krisch. (Archiv für das Eisenhüttenwesen, 1939, vol. 13, Oct., pp. 175-178). The author presents and explains a convenient form of diagram by means of which the elongation of a steel specimen with a diameter/length ratio of 1 : 10 can be instantly determined when the elongation and reduction in area of a similar specimen with a diameter/length ratio of 1 : 5 are known. He compares the results obtained in practice with those obtained using the diagram for converting the elongation of about 800 specimens of chromium-nickel, chromium-molybdenum and chromium-nickel-molybdenum steels, and finds that in over 75% of these there was a difference of less than  $\pm 1\%$  elongation in the results obtained.

**The Conversion of Elongation on Fracture from One Specimen Length to Another Using the Equation of M. Rudeloff and St. Gallik.** F. Uebel. (Archiv für das Eisenhüttenwesen, 1939, vol. 13, Oct., pp. 179-181). The author found that he did not obtain correct results when he applied the Rudeloff-Gallick equation for the conversion of the elongations of two heat-treated alloy-steel specimens from a diameter/length ratio of 1 : 5 to that of 1 : 10. He discusses the reasons for this and explains why the application of this equation is limited to steels in the as-rolled state.

**The Methods of Determining Stresses with X-Rays.** H. Möller. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1939, vol. 21, No. 20, pp. 295-308). The author discusses the relationships between the stresses, the lattice constants and the distance between the interference lines in different radiographic methods of determining stresses in steel, and examines the accuracy of the results obtained by these methods. He also determines the constants to be used in the stress calculations for iron and steel when gold or silver is used for calibration.

**The Determination of Surface Stresses from a Single Radiograph.** H. Möller and H. Neerfeld. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1939, vol. 21, No. 19, pp. 289-293). The authors describe an X-ray technique by which, using only one oblique radiograph, they can determine the position and value of the principal stresses at the surface of a stressed steel specimen.

**Elastic Anisotropy and Radiographic Stress Measurement.** H. Möller and G. Martin. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1939, vol. 21, No. 17, pp. 261-269).

Equations have been developed for measuring stresses in steel by X-rays based on Voigt's theory that under elastic stress the individual crystals making up a structure all suffer equal deformation, but test data obtained using known stresses were found not to be in agreement with this theory. The authors therefore undertook an investigation by X-ray elongation measurements with the object of checking the theory of Reuss that all crystals making up the structure are subjected to equal stress; they found that their results were not in agreement with the Reuss theory. From their own X-ray observations the authors calculated new values for the elasticity modulus and Poisson's ratio; these they propose to use in future X-ray elongation determinations, as they consider that they represent the true conditions more accurately than do those determined by mechanical measurements. These new values are: Modulus of elasticity ( $E_r$ ) = 22,030 kg. per sq. mm., and Poisson's ratio ( $\nu_r$ ) = 0.374. In conclusion they consider how stress measurements are affected by the application of these new values.

**Some Fatigue Problems of the Railroad Industry.** R. W. Clyne. (Metals and Alloys, 1939, vol. 10, Oct., pp. 316-323). The author studies the causes of fatigue cracks in leaf and spiral springs and in wagon axles on the American railways. In most cases it is found that the starting point of a crack is a notch or some form of surface discontinuity, produced either mechanically or chemically, which causes a concentration of stress. In conclusion he gives some particulars of a fatigue-testing machine for the testing of cast-steel side frames.

**Fatigue Tests of Wire.** C. P. Wampler and N. J. Alleman (Wire and Wire Products, 1939, vol. 14, Nov., pp. 649-653). After pointing out the advantages of having available some means of performing a fatigue test on wire the surface of which is in the as-received condition, the authors describe their investigation, which had the following objects: (a) To determine the effect of straightening wire specimens preparatory to testing in the rotating-strut machine; (b) to show the effect of different conditions of surface upon the fatigue strength of two materials of ordinary commercial finish; and (c) to check the reliability of the rotating-strut machine by comparing results obtained with it with those obtained with a vibratory (constant-strain) machine and with a high-speed rotating-cantilever-beam machine. They came to the following conclusions: (1) The rotating-strut machine offers a convenient and relatively inexpensive means of testing wire or rod  $\frac{1}{16}$  to  $\frac{3}{16}$  in. in dia. without removing the original surface of the specimen; (2) the methods of applying the load and calculating the stress used for this machine are reliable; (3) the condition of the surface of the specimen has a marked effect on the fatigue strength, that of machined and polished specimens being much higher than that of those in the as-received condition; and (4) the straightening of a brass or soft steel rod by giving it a permanent elonga-



tion of 0.10% has no appreciable effect upon its fatigue strength, and this shows that these materials can be straightened for tests in the rotating-strut machine without affecting the results obtained to any marked extent.

**Fatigue Problems in the Electrical Industry.** R. E. Peterson. (Metals and Alloys, 1939, vol. 10, Sept., pp. 276-279). The author describes and illustrates a number of failures in service of crankshafts, journals and gear teeth of electricity-generating machinery and describes some of the measures adopted to prevent their recurrence.

**Electrical Methods of Metal Testing.** (Metal Industry, 1939, vol. 55, Nov. 3, pp. 391-392). Descriptions are given of some electrical measuring instruments now available to the metal industry. The first is a fatigue tester for testing the quality of steel bars and non-magnetic metals. The second is for testing the hardness of thin sheets and foils down to 0.02 or 0.03 mm. in thickness. The third is used for measuring the thickness of foil; this instrument can be used when the metal is in motion and the measurements are made without contact with the metal; the actual thickness is measured independently of any lacquer, varnish or paper covering. A particular application of this instrument is at a rolling mill, to show any departure from the required thickness. The fourth instrument described is intended for measuring the thickness of any non-magnetic coating on a magnetic base.

**The Depth-Hardening of Chromium-Molybdenum and Chromium-Nickel Case-Hardening Steels.** A. Pomp and A. Krisch. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1939, vol. 21, No. 21, pp. 309-326). The investigation of the hardness, tensile and notched-bar-impact values of the chromium-molybdenum heat-treatable steels previously described (*see* Journ. I. and S.I., 1938, No. II., p. 322 A) has been extended to cover chromium-molybdenum and chromium-nickel case-hardening steels. In the investigation here reported the authors carried out a similar series of tests on specimens from 5 to 60 mm. in dia. After applying the same heat treatment to a series of specimens covering this range of sizes, it was found that the test results of the small-diameter specimens were as a rule higher than those specified by the German Air Ministry for the particular class of steel and those pertaining to the large-diameter specimens were lower. The authors present micrographs of the specimens tested and complete tables of analyses and test results.

**Classifying Steels by Spark Testing.** G. E. Gordon and E. A. Reid. (Iron Age, 1939, vol. 144, Oct. 19, pp. 38-42). The authors describe the characteristics of the sparks produced from different qualities of steel when an abrasive wheel revolving at high speed is pressed against them and by diagrams and illustrations they show how these characteristics can be used to determine the presence, and in some cases the approximate quantity, of carbon, silicon, chromium and molybdenum present.

**The Ageing of Plastically Deformed Material.** A. A. Zolotarev. (Metallurg, 1939, No. 4-5, pp. 77-82). (In Russian). The experimental work was carried out on Bessemer rail steel (0.40% of carbon, 0.75% of manganese, 0.06% of phosphorus, 0.05% of sulphur). Before cutting out the test-pieces the steel was annealed at 830° C. for 40 min. The effect of prolonged (up to 224 days) elastic deformation (bending) on the impact strength, Brinell hardness and electrical resistance of the steel was investigated. The curves giving the change in the above properties show that the elastic bending stress caused a drop in the impact strength of up to 75% of the initial value with first an increase and then a slight decrease in hardness; after 66 days a rapid increase in the electrical resistance took place. It is interesting to note that the curve showing the variation in hardness also shows a slight falling off for the first 66 days, this being followed by a rapid rise to a maximum after a total of 110 days, the total increase amounting to some 40 Brinell units. The hardness peak is followed by a gradual decline.

**"Alnico" and Related Alloys—The Metallurgical Story.** E. F. Cone. (Metals and Alloys, 1939, vol. 10, Oct., pp. 293-297). The author describes the processes of manufacture and heat treatment in the production of the magnetic alloys "Alnico" and "Alnic" at the foundry of the Simonds Saw and Steel Co., Lockport, U.S.A. The approximate compositions of these alloys are: Alnico, nickel 20%, aluminium 12%, cobalt 5%, balance iron; and Alnic, nickel 25%, aluminium 12%, balance iron; in both the carbon varies between 0.02% and 0.06% and the silicon and manganese are each below 0.10%. These alloys are prepared in an electric furnace and cast to the required shape. They cannot be machined, rolled or drilled, and can be finished only by grinding.

**An Apparatus for Magnetic Testing at Magnetizing Forces up to 5,000 Oersteds.** R. L. Sanford and E. G. Bennett. (Journal of Research of the National Bureau of Standards, 1939, vol. 23, Sept., pp. 415-425). The authors describe an instrument called the "NBS High-*H* Permeameter" which has been designed for magnetic testing in the range of values of from 100 to 5,000 oersted. Specimens of permanent-magnet alloys with a cross-section up to  $1\frac{1}{2} \times \frac{3}{4}$  in. can be tested with it, and it is estimated that under ordinary conditions of routine testing the readings are accurate to within 1%. The apparatus is convenient and simple to operate and does not heat the specimen.

**A Fundamental Note on the Problem of the Effect of Mechanical Stresses on the Magnetic Properties of Iron.** H. Schlechtweg. (Technische Mitteilungen Krupp, Forschungsberichte, 1939, vol. 2, Sept., No. 13, pp. 167-170). The author presents a mathematical discussion of the effects of mechanical stresses on the magnetic properties of iron.

**The Abnormal Magnetic Properties of Hardenable Alloys.** H. Bumm. (Zeitschrift für Elektrochemie und angewandte physikal-

ische Chemie, 1939, vol. 45, Sept., pp. 671-674). The author reports on an investigation of the effect of different forms of heat treatment on the magnetic properties of two alloys containing iron 51.5% and 50.5%, nickel 35.5% and 34.5%, and copper 13% and 15% respectively.

**An Experimental Contribution to the Fundamentals of Ferro-Magnetism.** R. Haul and T. Schoon. (Zeitschrift für Elektrochemie und angewandte physikalische Chemie, 1939, vol. 45, Sept., pp. 663-671).

**The Effect of Lattice Deformation on Ferromagnetic Properties.** H. Schlechtweg. (Technische Mitteilungen Krupp, Forschungsberichte, 1939, vol. 2, Sept., No. 13, pp. 163-166; Metallwirtschaft, 1939, vol. 18, Nov. 10, pp. 900-903). The author reviews some experimental results obtained and theoretical deductions which have been made during the last ten years relating to the effects of lattice deformation on the magnetic properties of iron.

**Steels for High-Temperature Service and Their Testing.** A. E. White. (Bulletin of the American Society for Testing Materials, 1939, Oct., pp. 15-19). The author describes some of the methods by which the properties of steel at high temperatures are determined, with special reference to short-time creep tests, stress rupture tests and tests for surface stability.

**Investigations of the Shape of Time-Elongation Curves for Various Steels with a New Creep-Testing Apparatus.** H. Esser and S. Eckardt. (Archiv für das Eisenhüttenwesen, 1939, vol. 13, Nov., pp. 209-220). The authors describe an apparatus which they developed for making creep tests; this apparatus incorporates an automatic temperature controller and an automatic elongation recorder. With this machine the authors then obtained time-elongation curves for two carbon steels with different sizes of austenite grains, one molybdenum steel and one chromium-molybdenum-vanadium steel at temperatures of 450° and 500° C. They found that in all four cases parabolic curves were produced, with the result that, using logarithmic ordinates and abscissæ, there was a straight-line relationship between the time and the elongation which could conveniently be used for extrapolation. By the application of these results the authors were able to determine from the results of a 10-12-hr. test whether a steel would pass the 45-hr. creep test specified in the German Engineering Standard Test A 117/118.

**The Solubility of Nitrogen in Molten Iron-Silicon Alloys.** J. C. Vaughan, jun., and J. Chipman. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1109: Metals Technology, 1939, vol. 6, Oct.). The authors report on a study of the solubility of nitrogen at atmospheric pressure in molten iron containing up to 15.8% of silicon. They found that in the temperature range 1600-1660° C. the solubility of nitrogen amounted to 0.041% in pure iron. The solubility increased to 0.046% as the silicon content was increased to 1-2%, and, as the silicon was further



increased up to 15.8%, the solubility decreased down to 0.01%. Their observations indicated the formation of an iron nitride and an iron silicide in solution and of a silicon nitride of limited solubility.

**Progress in Metallurgy : The Science of Alloys.** A. B. Kinzel. (Journal of the Franklin Institute, 1939, vol. 228, Sept., pp. 293-318). The author makes a rapid survey of the development of alloys, both ferrous and non-ferrous, from the earliest times.

**The Effect of a Low Copper Content on the Strength Properties of Structural Steel.** E. Houdremont, H. Bennek and H. Neumeister. (Archiv für das Eisenhüttenwesen, 1939, vol. 13, Sept., pp. 137-148). The authors discuss the effects of additions of up to 0.5% of copper on the properties of German structural steel St 52. An examination of the literature shows that the presence of such a low percentage of copper has practically no effect on the properties of pure iron and of ordinary mild steel which has been cooled slowly, but as the rate of cooling increases, the effect of the copper becomes more evident by the improvement in the tensile strength. They report on a series of tests on specimens containing carbon 0.17%, silicon 0.5% and manganese 1.5%, some of which contained 0.15% and others 0.45% of copper. The results showed that the elastic limit and tensile strength of the latter were higher than those of the former by 1-4 kg. per sq. mm. and by 2 kg. per sq. mm., respectively. The authors' general conclusions respecting the addition of up to 0.5% of copper to structural steel St 52 are : (1) The mechanical properties are improved but the improvement may be restricted by the presence of other elements ; and (2) the addition of copper has no deleterious effect upon the welding properties.

**Rôle of Nickel in the Machine Tool Industry.** J. W. Sands and D. A. Nemser. (Metals and Alloys, 1939, vol. 10, Sept., pp. 260-268 ; Oct., pp. 311-315). After touching upon the improvements in the performance of machine tools during the last ten years, the authors show that these are in a large measure due to the improved properties of the cutting tools. They then consider the fundamental properties of cast iron, show what effect the addition of nickel has on its cutting properties, and describe the forms of heat treatment which will bring these out to the full. In the concluding part the authors discuss the present state of the development of nickel steels with and without additions of chromium, molybdenum and vanadium, and present tables showing the analyses, heat treatment, properties and applications of a number of nickel alloy steels and nickel bronzes.

**Investigations of the Effect of the Vanadium and Chromium Contents of Low-Alloy High-Speed Steels.** R. Fizia, K. Gebhard, F. Rapatz and R. Scherer. (Stahl und Eisen, 1939, vol. 59, Aug. 31, pp. 985-990). After reviewing the literature relating to the effect of additions of chromium and vanadium on the cutting properties and life of high-speed steels, the authors describe some machining tests undertaken to determine the effects of additions of 4-6% of



vanadium on the cutting properties of steels containing about 4% of chromium plus (a) 3% of molybdenum, (b) 4% of tungsten, or (c) 4% of tungsten and 2% of molybdenum. A second series of tests was made to study the effect of additions of 4–12% of chromium on steels containing 1% of molybdenum and 2.5% of vanadium. The results showed that the tungsten and molybdenum contents could be reduced if vanadium were added, but after 2.5–3.0% of vanadium was reached no further improvement in the cutting properties was obtained. It was also confirmed that the previously established limit of about 4% of chromium was the most which could be added to the known tungsten-molybdenum tool steels in order to obtain any improvement in their performance.

**The Properties and Application of Acid-Resisting Chromium and Chromium-Nickel Cast Steel.** F. Schulte. (Giesserei, 1939, vol. 26, Sept. 22, pp. 477–484). In this review of the properties of the corrosion- and acid-resisting chromium-iron alloys the author shows that castings containing 14–18% of chromium have good mechanical properties, are unaffected by either fresh or sea water, but are not very resistant to acids. For applications requiring special strength the chromium-manganese steels can be used. The author deals more fully with the high-chromium steels, as these have good acid- and wear-resisting properties. These have, however, a limited application, as their strength is not so high. In conclusion he discusses some of the chromium-nickel steels which offer a high resistance to sulphuric and hydrochloric acids.

**Phosphorus in Steel.** C. H. Lorig and D. E. Krause. (Iron Age, 1939, vol. 144, Oct. 19, pp. 33–37, 88; Oct. 26, pp. 28–31). The authors report on the results of an investigation at the Battelle Memorial Institute on the mechanical and corrosion-resistance properties of specimens of various qualities of steel sheet containing controlled quantities of phosphorus varying from 0.006% to 0.59%. They find that both the tensile strength and the yield strength of plain and of alloyed steels are increased by a small increase in the phosphorus content and that, with low-carbon steels, this increase can be obtained with but little loss in ductility. The addition of phosphorus also increases the corrosion-resistance of steel.

**The Effect of Phosphorus on the Properties of Pearlitic Cast Iron.** A. Thum and O. Petri. (Archiv für das Eisenhüttenwesen, 1939, vol. 13, Sept., pp. 149–153). The authors give an account of an investigation of the effect of the presence of up to 1% of phosphorus on the mechanical properties of pearlitic cast iron containing carbon 3%, silicon 2%, manganese 0.5–1.0% and sulphur 0.04% in some specimens and 0.13% in others. The results showed that : (1) The tensile and bend strengths improved with increasing phosphorus content up to about 0.4%, above which content these strengths decreased ; (2) cast iron containing about 0.5% of combined carbon and exceedingly little phosphorus had a high impact strength, but only a slight increase in the phosphorus content caused this to

decrease rapidly ; (3) cast iron with a normal phosphorus content had the highest impact value when the structure was pearlitic ; (4) impact-bend tests on parallel and notched specimens showed that a high phosphorus content produced a high notch-sensitivity ; and (5) the effect of the phosphorus was not influenced by increasing either the sulphur or the manganese content.

**The Quality of Steel in Relation to Hot Working Properties.**

H. A. Dickie. (Journal of the Birmingham Metallurgical Society, 1939, vol. 19, Sept., pp. 98-106). The author surveys the effects of composition, temperature, process of manufacture, impurities and the addition of copper on the hot-working properties of steel.

**A New Special Shock-Resisting Steel.** (Industrial Power and the Fuel Economist, 1939, vol. 15, Oct., p. 299). Some particulars are given of the mechanical properties of K.L. "Stronger Steel" and K.L. "High Shock" steel manufactured by Kryn and Lahy (1928), Ltd., of Letchworth.

**Steel Standardization.** A. L. Hartley. (Iron Age, 1939, vol. 144, Sept. 7, pp. 27-33 ; Sept. 14, pp. 61-66 ; Sept. 21, pp. 46-49, 81 ; Oct. 5, pp. 31-33, 65-66 ; Oct. 12, pp. 33-37). In this series of articles the author makes suggestions for the extension of the S.A.E. (Society of Automotive Engineers) system of standardising steels. The scheme he outlines has six objectives, namely : (1) To classify the general types of steel required for parts to be fabricated from stock bars and forgings ; (2) to show the physical and metallurgical requirements of each of the general types ; (3) to analyse the relative merits and net costs of the stock bars of various finishes ; (4) to establish purchasing specifications ; (5) to establish a material inspection programme ; and (6) to establish a code system for each of the grades of steel and for each heat treatment. In Part I. he deals with the first objective and presents tables of the analyses and characteristics of a large number of S.A.E. steels. In Parts II. and III. he deals with the second objective and considers the steel required by the machine tool manufacturer. In the fourth part the author outlines the properties which should be included in specifications and gives some examples of proposed purchasing specifications. In the concluding part he suggests a programme for the inspection of materials and a code system for indicating qualities of steel and heat treatments on records and drawings.

## METALLOGRAPHY AND CONSTITUTION

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(Continued from pp. 47 A-52A)

**A Micro-Fracturing Machine for the Photomicrographic and Cine-Micrographic Investigation of Materials.** T. Pöschl. (Archiv für das Eisenhüttenwesen, 1939, vol. 13, Oct., pp. 189-192). The author describes a machine in which small specimens of steel can be submitted to a gradually increasing bending load until fracture occurs. The load may be applied by hand or by electric motor, and the machine is designed for clamping on to the stage of a microscope. If this machine is fitted to a microcinematographic camera a continuous series of micrographs can be obtained of a specimen from the moment of application of the load up to the moment of complete fracture, and it is therefore a valuable aid to the study of the process of slip and of the changes in structure which occur during the breaking of a specimen.

**The Magnetic Detection of Faults in Alloys.** J. Fluvot. (Génie Civil, 1939, vol. 115, Nov. 4, pp. 333-337; Nov. 11, pp. 355-357). The author discusses the apparatus and technique employed in the magnetic-powder method of detecting cracks and faults in parts of internal combustion engines.

**Some Aspects of Radiographic Sensitivity in Testing with X-Rays.** H. H. Lester. (Bulletin of the American Society for Testing Materials, 1939, Oct., pp. 33-40). The author describes a number of experiments on the optimum focal distances for good definition when using commercial X-ray tubes, and discusses the results obtained.

**The Recrystallisation Textures of the Face-Centered Iron-Nickel-Copper Alloys.** H. G. Müller. (Zeitschrift für Metallkunde, 1939, vol. 31, Oct., pp. 322-325). The author refers to methods by which a "texture" can be imparted when desired to iron-nickel-copper alloys. The alloy is said to have a "texture" when the orientation of its crystals is not random, but regular. He reports on an investigation by means of X-rays of the recrystallisation process in specimens of severely cold-worked iron-nickel-copper alloy and of the effect of the annealing temperature on this process. In his discussion of the results obtained he examines the effect of the addition of small quantities of the soluble metals nickel and copper on the orientation of the crystals.

**Reaction Kinetics in Processes of Nucleation and Growth.** W. A. Johnson and R. F. Mehl. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1089: Metals Technology, 1939, vol. 6, Aug.). In this mathematical discussion the authors consider the data used for plotting isothermal reaction

curves representing reactions in which the rate of nucleation and the rate of radial growth of the nodules both remain constant. Proceeding on the assumption that the reaction proceeds by nucleation and growth and that the distribution of nuclei is random without regard to structure, the authors apply these curves to the analysis of the process of the freezing of steel.

**Kinetics of Austenite Grain Growth in Cast and Forged Steel with Additions of Aluminium, Vanadium and Titanium.** K. A. Malyshev. (*Metallurg*, 1939, No. 6, pp. 30-47). (In Russian). High-frequency-furnace medium-carbon steel heats, produced as far as possible under uniform conditions, were used in this investigation of the austenite grain growth in cast and forged steel. Aluminium was added to the ladle, but the ferro-vanadium and ferro-titanium were added to the furnace after deoxidation of the steel with silicon and manganese. The additions included aluminium 0.05%, 0.1% and 0.2%, vanadium 0.23% and titanium 0.1%. The cast and forged cube-shaped specimens were first normalised for 2 hr. at 850° C., followed by air-cooling. They were then packed in powdered fireclay containing some charcoal and heated at the rate of 160-180° C. per hr. to temperatures of 850-1200° C. (in steps of 50° C.), at which they were then held for periods of 0.5-24 hr., and the kinetics of grain growth were studied by examining the excess ferrite network formed on cooling in air. The effects of a preliminary heating for 9 hr. to 900°, 1000°, 1100° and 1200° C. on subsequent austenite grain growth at 850° C., and that of repeated heating through the  $Ac_1$ - $Ac_3$  range on the grain growth at 850° C. were also investigated. The numerous experimental results obtained lead to the following general conclusions: (1) On heating above the critical range the fine austenite grains in each heat exhibit a certain stability; this is the incubation period. (2) On raising the temperature or prolonging the heating, the incubation period is followed by growth of the individual grains at the expense of their neighbours. (3) Small additions of aluminium, vanadium and titanium prolong the incubation period, this manifesting itself in a 100-150° C. rise in the temperature at which grain growth sets in. (4) Fine grains have the maximum stability in cast steel. (5) Forging reduces the incubation period and also the grain-growth temperature by some 50-100° C. (6) Among the steels with special additions, that with 0.23% of vanadium has the most noteworthy behaviour, the fine grain remaining practically unaffected up to 900-950° C. by preliminary forging or heat treatment and retaining a uniformity in grain size up to 1200° C. As compared with this, the effect of aluminium or titanium additions is more or less destroyed by preliminary forging. (7) Preliminary overheating of aluminium- or vanadium-bearing steels can be readily corrected by normalising at a temperature slightly above  $Ac_3$ . (8) Preliminary heat treatment in general reduces the stability of fine-grained austenite, except in the case of aluminium-bearing



steel in which heating to 1100–1200° C. results in improved stability of the austenite grain size.

**Investigation of Chromansil Steel EI75.** G. Nazarova and V. Babaev. (Stal, 1939, No. 3, pp. 45–48). (In Russian). The analyses of the heats were within the following limits: Carbon 0.31–0.35%, silicon 1.32–1.60%, chromium 1.26–1.31%, manganese 0.97–1.08%, phosphorus 0.021–0.024% and, as an impurity, nickel 0.18–0.32%. The steel was free from defects due to melting practice. The critical points were:  $Ac_1$  775–780° C.,  $Ac_3$  870–880° C.,  $Ar_1$  665–670° C. and  $Ar_3$  720° C. An investigation of the austenite in this steel on heating up to 1060° C. showed that it was insensitive to overheating, and that consequently the steel permits of a wide heat-treating range. Hardenability tests gave satisfactory results. The optimum heat treatment consists of quenching from 900–920° C. and tempering at 260–280° C. for 2.5–3 hr. The mechanical properties in a direction along and across the grain were determined.

**Magnetic Analyses of Transformations in a Cold-Worked 18-8 Alloy.** R. Buehl, H. Hollomon and J. Wulff. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1120: Metals Technology, 1939, vol. 6, Oct.). The authors examined by means of magnetic-moment measurements the transformations which occur during the heating and cooling of specimens of 18/8 stainless steel containing different amounts of ferrite produced by cold-rolling. They came to the following conclusions: (1) A cold-reduction of 50% produced about 9% by volume of ferrite in austenitic 18/8 stainless steel containing 0.08% of carbon. A phase tentatively identified as iron carbide was formed during cold-working. (2) Annealing above 250° C. caused this phase to disappear, but new phases with successively lower Curie points appeared subsequently at higher temperatures. (3) Annealing at up to 440° C. released some of the internal stresses, thereby slightly increasing the magnetism of the alloy, but without increasing the ferrite or austenite contents. (4) Annealing at above 440° C. initiated the  $\alpha$ - $\gamma$  transformation. (5) During annealing in the range 600–800° C. non-magnetic carbide precipitation occurred primarily in the grain boundaries of the material. (6) The annealing of the cold-worked stainless steel in the range 800–1100° C. for periods of 1–2 hr. followed by quenching enabled a phase—probably a carbide—with a Curie point of 168° C. to be identified.

**Some Generalisations Regarding the Equilibrium Diagrams of Ferrous Alloys.** A. P. Gulyaev. (Metallurg, 1939, No. 6, pp. 3–6). (In Russian). The effects of alloying elements in binary alloy equilibrium diagrams are subdivided into four groups from the point of view of the displacement of the critical points and the effect on the  $\gamma$  region. A survey of available data shows that the effect of alloying elements in widening the  $\gamma$  region (the limits of the  $\alpha + \gamma$  region) is directly connected with the atomic weight of the element. In the case of alloying elements which lower and those which raise

the  $A_4$  point, the position of the outer limit of the  $\alpha + \gamma$  region always occurs at about 2 atomic-% of the element in alloys with the usual amount of impurities.

**The Iron-Cobalt-Beryllium System.** W. Köster. (Archiv für das Eisenhüttenwesen, 1939, vol. 13, Nov., pp. 227-230). The author discusses the hardness and magnetic properties in relation to the equilibrium diagrams for the ternary system iron-cobalt-beryllium. For this purpose he prepared one series of specimens containing 5%, 10%, 15%, 20% and 25% of cobalt and three further series in which the iron/cobalt ratios were kept at 2:1, 1:1 and 1:3, respectively; the beryllium content varied between 2% and 20%.

**Magnetic Studies in the Ternary System Fe-Ni-Al.** J. L. Snoek. (Laboratoria Philips' Gloeilampenfabrieken, Separaat 1411: Physica, 1939, vol. 6, Apr., pp. 321-331). The author tested the magnetic properties of a series of alloys in which equal atomic percentages of nickel and aluminium were present and the iron content was raised in stages of 10%. After quenching from 1200° C. and annealing at 500° C. it was found that the degree of magnetic saturation was approximately proportional to the iron concentration in atomic-%. When the specimens were cooled slowly from 500° C. and annealed at the same temperature, it was found that the straight-line relationship did not hold between 10 and 60 atomic-% of iron, a phenomenon which the author attributed to the occurrence of a face-centered phase.

**The Iron/Iron-Silicide/Tungsten Constitutional Diagram.** R. Vogel and H. Töpker. (Archiv für das Eisenhüttenwesen, 1939, vol. 13, Oct., pp. 183-188). The authors investigated six sections of the iron/iron-silicide/tungsten system. The compound FeSi forms a pseudo-binary phase with tungsten, in which a ternary congruent-melting compound FeWSi can be detected and from which a ternary incongruent-melting compound  $\text{FeW}_2\text{Si}$  can probably be formed. The compound  $\text{Fe}_3\text{Si}_2$ , which can exist in the solid state in the iron-silicon system, is capable of forming a ternary solid solution in the continuous solid-solution series  $\text{Fe}_3\text{Si}_2$ -FeWSi. This series has at one end the composition tungsten 25.75%, silicon 19.55% and iron 54.7%, which corresponds approximately with the formula  $\text{Fe}_7\text{WSi}_5$ . The diagram of the process of crystallisation is characterised by three four-phase transition planes and one four-phase eutectic plane. The formation of the ternary solid-solution phase proceeds along a fifth four-phase plane, and with the  $\text{Fe}_3\text{Si}_2$  (a compound present in the solid state in the iron-silicon system) forms a continuous series of solid solutions. The authors also present two isothermal iron/iron-silicide/tungsten constitutional diagrams, one at 1175° C. and one at room temperature.

## CORROSION OF IRON AND STEEL

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(Continued from pp. 53 A-59 A)

**A Study on the Corrosion of Iron by Electron Diffraction.** S. Miyake. (Scientific Papers of the Institute of Physical and Chemical Research, Tokyo, 1939, vol. 36, Oct., pp. 363-370). The author studied the process of the corrosion of iron immersed in water and in a 1% solution of common salt by the electron diffraction method. In addition to the well-known rust products, he detected the presence of an unknown substance. This substance gave a two-ring diffraction pattern which closely resembled the film assumed by Bengough in his film-distribution theory. The author believes this substance has a composition between  $\gamma\text{-Fe}_2\text{O}_3\cdot\text{H}_2\text{O}$  and  $\gamma\text{-Fe}_2\text{O}_3$ .

**The Alkali-Resisting Properties of Mild Steel in Relation to Ageing Tendency, Heat Treatment and Aluminium Content.** F. Nehl and W. Werner. (Stahl und Eisen, 1939, vol. 59, Oct. 19, pp. 1155-1157). The authors report on an investigation of methods of determining and of increasing the resistance of mild steel to the attack of alkalis. Steels of six different compositions were tested, the analyses of which were within the following limits: carbon 0.06-0.23%, silicon 0.0-0.26%, manganese 0.31-0.69%, phosphorus 0.008-0.047%, sulphur 0.025-0.044% and aluminium 0.003-0.048%. The authors came to the following conclusions: (1) There was no relationship between either the notch-impact-sensitivity in the ordinary annealed state or the same property in the artificially aged state and the resistance to alkali attack; (2) the reduction in notch-impact-sensitivity due to ageing was not a measure of the alkali resistance; (3) low-carbon steels were less liable than high-carbon steels to intercrystalline corrosion caused by alkali attack, and the carbon content of steels subject to alkali attack should therefore not exceed 0.15%; (4) when aluminium was added to increase the alkali resistance of the steel, the aluminium content should exceed 0.04%; (5) certain forms of heat treatment imparted alkali-resisting properties to aluminium-killed steels and to steels low in aluminium; and (6) steel with a decarburised surface was highly susceptible to alkali attack.

**The Surface Attack, Intercrystalline Grain-Precipitation and Electrochemical Potential of the Stainless Chromium-Nickel and Chromium-Manganese Steels.** E. Maurer. (Korrosion und Metallschutz, 1939, vol. 15, Sept., pp. 285-294). The author describes an investigation which had the object of determining whether the time-potential curve of chromium-nickel and of chromium-manganese steel in 1N sulphuric acid could be used to assess the cor-

rosion resistance of these steels. The results showed that there was only an approximate relationship between the potential and the degree of corrosion resistance. When the potential was negative there was comparatively little corrosion, whilst there was much more corrosion with a positive potential. He also found that the occurrence of intercrystalline corrosion did not affect the time-potential curve. His general conclusion was that the electrochemical behaviour of these steels does not offer a means of determining their resistance to corrosion, but that for this purpose direct tests with loss-in-weight determinations must be made.

**The Nature of Passivity in Stainless Steels and Other Alloys.**

**III. Time-Potential Data for Cr-Ni and Cr-Ni-Mo Steels.** H. H. Uhlig. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1121: Metals Technology, 1939, vol. 6, Oct.). Continuing his study of the nature of passivity in stainless steels (*see* Journ. I. and S.I., 1939, No. II., p. 236 A), the author in this part presents the results obtained in the measurement of the potentials of some stainless steels in relation to time, with special reference to the effect of additions of molybdenum. The electrolytes used were 4% sodium chloride solution (both aerated and free from oxygen), water and oxygen-free water. The specimens were first activated by immersion for 10 min. in hydrochloric acid. He found that in aerated sodium chloride solution the alloy containing molybdenum rapidly became passive again, whereas the 18/8 stainless steel containing no molybdenum only recovered passivity to a limited extent.

**A Contribution to the Study of the Corrosion-Resistant Properties of Cr-Mn Steels.** A. I. de Sy. (Revue de Métallurgie, Mémoires, 1939, vol. 36, Sept., pp. 389-399). The author subjected five chromium-manganese steels of different compositions to corrosion tests by exposure to various electrolyte solutions, and by electrolytic attack; 18/8 chromium-manganese steel of ferritic-austenitic structure proved superior to austenitic 15/12 and 15/9 chromium-manganese steels, whether they contained nickel or not. All steels tested were subject to intercrystalline corrosion when exposed to a mixture of 10% sulphuric acid + 10% copper sulphate; 18/8 chromium-manganese steel, however, was much less rapidly attacked by this reagent. All steels studied showed rust stains after intermittent immersion in 2% sodium chloride solution for 100 hr. Finally, the author shows, in the way described previously (*see* Journ. I. and S.I., 1939, No. II., p. 304 A), that the intergranular corrosion of reheated specimens is due to the low chromium content of the grain boundaries.



## ANALYSIS

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**Analysis of Iron Castings.** (Machinery, 1939, vol. 54, Sept. 28, pp. 777-779). A brief illustrated description is given of the equipment used in the laboratories at the River Rouge Plant of the Ford Motor Co. for making rapid spectrographic analyses of samples of iron taken from the cupolas before casting.

**Perchloric Acid. Part V.** C. M. Johnson. (Iron Age, 1939, vol. 144, Oct. 12, pp. 30-31). Continuation of a series of articles (see Journ. I. and S.I., 1939, No. II., p. 239 A). In the fifth part of this series the author describes the procedures, using perchloric acid, for the determination of metallic iron in high-alloy chromium, molybdenum, tungsten and vanadium steels, in 42% nickel steel, in ferro-manganese and in iron ore.

**An Apparatus for the Determination of Carbon in Iron, Steel and Iron Alloys by the Baryte Process.** H. Kempf and K. Abresch. (Archiv für das Eisenhüttenwesen, 1939, vol. 13, Sept., pp. 135-136). The authors point out that the baryte process for the determination of carbon in steel, in which the sample is oxidised in a stream of oxygen and the carbon dioxide is absorbed in a baryte solution is particularly applicable when the sample is an iron alloy difficult to oxidise. They draw attention to the difficulties encountered in conducting the analysis, in particular that of excluding the carbon dioxide in the atmosphere, and describe a form of apparatus with which these difficulties are overcome.

**The Rapid Determination of Chromium and Manganese in Steel.** K. Dietrich. (Metallwirtschaft, 1939, vol. 18, Sept. 30, pp. 811-813). The author describes photometric methods for the determination of chromium and manganese in steel. Chromium is determined after oxidation to perchromic acid as suggested by Pinsl (see Journ. I. and S.I., 1937, No. I., p. 96 A). The present author introduces perchloric acid as an oxidising agent, however, in order to avoid certain complications experienced when using ammonium persulphate according to Pinsl. The latter oxidising agent proved to be superior to the former, however, in the oxidation of manganese to permanganate, necessary for the photometric determination of this metal. The determination of chromium can be carried out in 16 min. and that of manganese in 10 min. The error for chromium is  $\pm 0.03\%$ , for manganese  $\pm 0.02\%$ . The colours remain constant for about three days for both metals, so that the methods described are also suitable for serial tests.

**The "Evolution" Method for Determining Sulphur in Mild Steel.** T. P. Hoar and G. E. S. Eyles. (Analyst, 1939, vol. 64, Sept., pp. 666-667). The authors refer to the routine method of determining the sulphur in mild steel which consists of dissolving

the steel in hydrochloric acid, passing the evolved gases into ammoniacal cadmium chloride or zinc sulphate solution, filtering off the sulphide precipitate, dissolving it in a known excess of acid iodine solution, and titrating back the excess of iodine. They state that, for rapidity, the filtration is often omitted and the entire contents of the absorption tube are washed directly into the acid iodine. They give reasons why a considerable error may arise from this procedure, but show that this error can be entirely eliminated by cooling the acid iodine solution with added ice before the ammoniacal solution is washed in. They describe the procedure in detail and state that the sulphur determinations thus obtained are correct to within  $\pm 0.002\%$ .

**The Determination and Separation of Niobium and Tantalum in Steel by Precipitation with Phenylarsinic Acid or Sodium Bicarbonate in the Presence of Hydrogen Peroxide.** H. Fücke and J. Daubländer. (Technische Mitteilungen Krupp, Forschungsberichte, 1939, vol. 2, Sept., pp. 174–178). The authors describe two quantitative methods for the separation and determination of tantalum and niobium in steel. The first is based upon the precipitation of the tantalum in a hydrogen-peroxide/sulphuric-acid solution by adding phenylarsinic acid. In the second the oxides of the two metals in a hydrogen-peroxide/sulphuric-acid solution are separated by precipitating the tantalum with sodium bicarbonate. In conclusion a method of determining the combined content of the two metals as well as the silicon content of the steel is given.

**Contribution to the Determination by Spectrum Analysis of Niobium and Tantalum in High-Alloy Steels.** O. Schliessmann. (Technische Mitteilungen Krupp, Forschungsberichte, 1939, vol. 2, Sept., pp. 185–190). The author describes and discusses the determination of niobium and tantalum in the high chromium-nickel steels by means of spectrum analysis and compares the accuracy of the results obtained with that of other methods. The method is applicable when the niobium content exceeds 0.1% and when the tantalum content exceeds 1%. The time required is 2–3 hr.

**The Photometric Determination and Separation of Niobium, Tantalum and Titanium in Steel and Iron Alloys.** P. Klinger and W. Koch. (Technische Mitteilungen Krupp, Forschungsberichte, 1939, vol. 2, Sept., pp. 179–185; Archiv für das Eisenhüttenwesen, 1939, vol. 13, Sept., pp. 127–132). The authors examined the colour intensities produced by titanium and niobium in hydrogen peroxide. The strongest colour effect was produced by titanium in dilute sulphuric acid, and by niobium in 100% sulphuric acid. They evolved a method based on colour-intensity differences in sulphuric acid of different concentrations by which determinations of niobium and titanium can be made when tantalic acid is also present. They also describe a rapid method of determining the titanium in steel by using chromotropic acid.

**The Determination of Tantalum and Niobium in Ferro-Tantalum, Ferro-Niobium and Ferro-Tantalum-Niobium.** K. Brüning, K. Meier and H. Wirtz. (*Metall und Erz*, 1939, vol. 36, Nov., No. 22, pp. 551-554). The authors describe a process for the accurate quantitative determination of tantalum plus niobium in iron alloys and then describe a crystallisation method of separating the two elements from the precipitate obtained in the first method.

**Contribution on the Determination of Phosphorus in Vanadium Slags.** E. Stengel. (*Archiv für das Eisenhüttenwesen*, 1939, vol. 13, Nov., pp. 205-207). The author studied several recently published methods for determining phosphorus in iron in the presence of vanadium and their applicability for the analysis of vanadium slags. He found that these methods were not altogether satisfactory for slags, but he developed an improved technique by which satisfactory precipitates and accurate results can be obtained. He describes this procedure in detail.

**An Instrument for Electro-Chemical Analysis.** (*Journal of Scientific Instruments*, 1939, vol. 16, Nov., pp. 358-559). A description is given of an instrument known as the "polarograph" which has been developed for the determination, both qualitatively and quantitatively, of most metals and many acids and organic substances in solution. The amount of solution required for each test is stated to be only 2 ml. and, should it be desired to obtain records under varying conditions of sensitivity, the test may be repeated several times using the same sample.

**Spectrum Analysis and its Application in the Examination of Ores and in Prospecting.** S. Landergren. (*Teknisk Tidskrift*, 1939, vol. 69, *Bergsvetenskap*, Sept. 9, pp. 65-68; Oct. 14, pp. 73-77). (In Swedish). The author discusses the theory and practice of spectrum analysis as applied in the geochemical laboratory for making quantitative analyses of ores.

**A Survey of Methods and Apparatus for Micro-Gas Analysis.** H. Hartridge. (*Journal of Scientific Instruments*, 1939, vol. 16, Oct., pp. 317-324). The author gives a general description of the principles and apparatus employed for the analysis of very small quantities of gas. These may be classified as "volumetric" and "physical" methods. In the first group there are: (a) Those in which the confining medium is mercury and solid reagents are employed; (b) those in which the confining fluid is either mercury or some other liquid and liquid reagents are employed; (c) those in which the confining liquid acts as a flotation medium for a small gas-containing vessel or "diver," fluid reagents being employed; and (d) those in which there is no confining fluid and the pressure of the gas is measured by a physical method. The physical methods which adapt themselves to micro-analysis are: (1) The spectroscopic examination of the emission spectra; (2) the measurement of the thermal conductivity of the gas; and (3) the determination of the dielectric constant of the gas.

## BOOK NOTICES

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(Continued from pp. 60 A-62 A)

BUELL, W. C., jun. "*The Open-Hearth Furnace. Its Design, Construction and Practice.*" Volume III. 8vo. Pp. x + 308. Illustrated. Cleveland, Ohio and London, 1939: Penton Publishing Co. (Price 22s.).

This is the third and final volume of a series dealing with the design and construction of open-hearth furnaces. The first volume, published in 1936, dealt with the refractories and the design and construction of the furnace, while the second volume, published in 1937, dealt with the metallurgical problems and the influence of design in carrying out the process.

The present volume is devoted to the several components of the open-hearth furnace system that are located below the charging floor, where, in comparison with the structure above the charging floor, the design is much more simple and the problems of refractory economy and maintenance are much less difficult, but where the factors of heat transfer and fluid flow are of equal importance. In the previous volumes, complete data are presented covering the design of 100-ton and 150-ton furnaces, but in the present volume, on account of the large number of limitations of space affecting the design of the principal components of the ancillary system of an open-hearth furnace and the infinite number of the arrangements and sizes of these components that are possible, design data are presented for only a 150-ton furnace. It should not prove difficult, however, by following the principles expounded by the author to select a design and layout of the ancillary system for a furnace of other than 150 tons capacity.

The book is well illustrated and contains an index to all tables, equations and illustrations appearing throughout the three volumes. The first line drawing in the present volume illustrates a typical layout of the ancillary system of a producer-gas-fired open-hearth furnace, indicating the position and designation of the critical areas and giving their approved nomenclature; throughout the volume this system of designation is used consistently which makes reference by the reader so much easier and makes for considerable brevity of expression.

The volume contains eighteen chapters, dealing in turn with fluid flow in the ancillary system; design, general layout and refractory construction of typical slag pockets; design of fantails; connecting flues, the short ducts that connect the regenerator outlets with the flue system proper; design of regenerator chambers; distribution and flow of fluids in regenerator chambers; checkerwork; heat exchange in regenerators; flues; waste-heat boilers; open-hearth furnace control; flow diagrams. In the final chapter an attempt is made to indicate the value of the economies which can be effected by following the principles expounded in the use of constructional materials and by close attention to the problems of fluid flow within the structure.

It can only be said that the series forms a complete work for the guidance of open-hearth furnace operators and designers which no reference library of any steel producing company can afford to be without. The manner in which the material is presented leaves nothing to be desired.



CHALMERS, B. "*The Physical Examination of Metals.*" Vol. I : "*Optical Methods.*" 8vo. Pp. viii + 181. Illustrated. London, 1939 : Edward Arnold & Co. (Price 14s.).

In so far as the majority of metallurgists are concerned, optical methods of the physical examination of metals have been mainly restricted to macroscopic and microscopic examination and to the use of simple optical levers for the observation of angular measurements such as are encountered in mirror galvanometers and extensometers.

In the present volume the author has effectively searched through the whole of applied optics, and gives easily readable and comprehensive descriptions of the various phenomena that might be of use to a metallurgist or engineer.

The book commences with a short but interesting introductory chapter, which is followed by a chapter on "Geometrical Optics." This chapter is particularly comprehensive, and sections are devoted, amongst other things, to the examination of surface irregularities by reflected light, and particulars are given of a method for the examination of the surface of tinplate. Further sections give particulars for the investigation of shape of surface, optical reflecting power, scratches on tinplate, &c., and various other applications of reflected light.

The third chapter deals with the application of interference phenomena. The author gives details of several methods for applying the interference effect to the measurement of relative movement. An instructive section then deals with the use of interference fringes as a method of testing the shape of metallic surfaces, on which the author has carried out a considerable amount of original research work. He has likewise attempted, and with some success, to obtain information concerning the shape and dimensions of exceedingly sharp edges, such as safety-razor-blade edges. A considerable amount of attention is also devoted to the relationships between the thickness of oxide films and the resulting colour.

The fourth chapter is mainly devoted to diffraction phenomena and, amongst other applications, the author deals with its application to the measurement of mesh size of fine screens and particle size of powders.

The book concludes with two chapters, one devoted to polarised light and its possible application to metallurgy, and the other a short chapter dealing in general with radiation of light and spectroscopic analysis.

The book is copiously illustrated with diagrams and a few photographs, all of which are particularly good and clear.

J. FERDINAND KAYSER.

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## REFRACTORY MATERIALS

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(Continued from pp. 66 A-67 A)

**30th Report of the Refractory Materials Joint Committee.** (Institution of Gas Engineers, 1939, Communication No. 218). This is the thirtieth report to the Council of the Institution of Gas Engineers on the research work carried out by the Joint Committee appointed by this Institution, the Society of British Gas Industries and the British Refractories Research Association. It is presented in four parts. The first comprises a summary of the whole report, the second sets forth the constitution of the Joint Committee and gives some general information on the scope of the work, the third part consists of the papers in which the various investigators report on their individual researches, and the last part consists of a paper dealing with a phenomenon observed in retort-house practice at the Tottenham gasworks. Abstracts of the individual papers making up the report will be found below.

**Refractories for Gas- and Coke-Burning Appliances.** L. R. Barrett and A. T. Green. (Thirtieth Report of the Refractory Materials Joint Committee: Institution of Gas Engineers, 1939, Communication No. 218, pp. 10-33). The special features of insulating firebricks are discussed, and calculations and instances are quoted to show the economies of fuel and time made possible by their use. The limitations of this material suggest that a composite brick should be developed, having the durability of a dense brick under adverse conditions of temperature fluctuations, flying slag particles and mechanical abuse, combined with the heat conservation of porous insulating bricks. Experience with thin coatings of glaze or cement on the hot face of insulating firebrick and some data on the power of refractories to reflect radiation are given, and the conditions surrounding the use of refractories in some town-gas-fired pottery and steel-heating installations are described.

**The Action of Steam and Sulphur Dioxide on Refractory Materials. Part I. The Action on Fireclay at 1200° C.** L. R. Barrett, N. E. Dobbins and A. T. Green. (Thirtieth Report of the Refractory Materials Joint Committee: Institution of Gas Engineers, 1939, Communication No. 218, pp. 33-45). An account is given of the changes occurring with a particular fireclay heated at 1200° C. for periods up to 222 hr. in atmospheres of oxygen, steam, sulphur dioxide and various mixtures of these gases.

**The Effect of Hydrocarbon Gases on Refractory Materials. Part VII. The Change in the Composition of Coal Gas when Passed Over Refractory Materials at 800° C.** E. Rowden. (Thirtieth Report of the Refractory Materials Joint Committee: Institution

of Gas Engineers, 1939, Communication No. 218, pp. 45-49). In a previous report attention was called to the fact that dry coal gas direct from the mains does not cause the disintegration of certain types of firebrick at about  $800^{\circ}\text{C}$ ., but that town gas from which the carbon dioxide has been removed can disrupt similar specimens in a relatively short period. In the present paper an account is given of the way in which the above observations have been extended by determining the changes in composition of the coal gas during its passage over fireclay specimens susceptible to disintegration.

**The Action of Alkalies on Refractory Materials. Part XII. The Effect of Heat on Refractory Materials Impregnated with Sodium Carbonate and Sodium Hydroxide.** F. H. Clews, H. M. Richardson and A. T. Green. (Thirtieth Report of the Refractory Materials Joint Committee: Institution of Gas Engineers, 1939, Communication No. 218, pp. 49-55). In previous experiments it has been observed that considerable expansion occurs when refractory materials are exposed to the vapour of sodium or potassium chloride at about  $1000^{\circ}\text{C}$ . The experiments here reported were devised to test whether, under suitable conditions, similar expansions occur with alkali compounds other than the chloride. In an endeavour to obtain a fairly uniform reaction, test-pieces were impregnated with sodium carbonate and sodium hydroxide solutions, dried and heated to  $1000^{\circ}\text{C}$ . for 5 hr. and the procedure repeated a number of times. Under these conditions expansion of fireclay and silica test-pieces occurred, but examination showed certain marked contrasts with the expansion produced by the action of sodium and potassium chloride vapour. The expansion observed in the present experiments is ascribed to a more or less uniform distension of the refractory due to the evolution of gas (carbon dioxide from the carbonate and steam from the hydroxide) in a material rendered deformable by chemical reaction with the sodium compounds.

**The Action of Alkalies on Refractory Materials. Part XIII. The Effect of Potassium Chloride Vapour on the Transverse Strength at  $1000^{\circ}\text{C}$ .** F. H. Clews, H. M. Richardson and A. T. Green. (Thirtieth Report of Refractory Materials Joint Committee: Institution of Gas Engineers, 1939, Communication No. 218, pp. 56-59). The effect of exposure to potassium chloride vapour on the transverse strength of a number of refractory materials held at  $1000^{\circ}\text{C}$ . was investigated. The vapour caused a weakening of all the materials tested. The fireclay materials were weakened but not appreciably softened, whereas the silica and siliceous products were markedly softened. This difference in behaviour was ascribed to the greater degree of liquefaction caused by the reaction of the potassium chloride with the silica and siliceous products compared with that occurring on reaction with the fireclay materials.

**Jointing Cements. Part IX. The Effect of Additions of Some Electrolytes on the Workability of Clay-Grog Mixtures.** F. H. Clews, H. M. Richardson and A. T. Green. (Thirtieth Report of

the Refractory Materials Joint Committee: Institution of Gas Engineers, 1939, Communication No. 218, pp. 59-65). In this paper experiments are described which had as their object the improvement of the working properties of clay-grog cement mixes by the addition of small amounts of electrolytes. The water-retaining capacity and the tendency to spread under vibration were used as a basis for assessing any change in the working properties. The electrolytes used included sodium hydroxide, ammonium hydroxide, hydrochloric acid and calcium chloride, and the clays used were a ball clay, a fireclay, and two types of bentonite. It was found that the working properties of clay-grog mixes, as indicated by the above characteristics, may be appreciably altered, and in some cases improved, by the addition of electrolytes. It was noted, for example, that the water-retaining capacity of mixes made up with 0.1 N and 0.05 N sodium hydroxide was superior to that made up with pure water.

**Jointing Cements. Part X. The Stability of Cement Mixes at 1300° C. Containing Uncalcined Kyanite.** F. H. Clews, H. M. Richardson and A. T. Green. (Thirtieth Report of the Refractory Materials Joint Committee: Institution of Gas Engineers, 1939, Communication No. 218, pp. 65-68). The results are presented of an investigation which had as its object the study of the effect of adding uncalcined kyanite to clay-sillimanite cements. An aluminous fireclay brick was used on which to prepare the joints, and the behaviour of the joints at 1300° C. under compressions of 10 and 30 lb. per sq. in. was observed. The general conclusion was that the addition of uncalcined kyanite was beneficial in counteracting the contracting tendency of the clay bond at high temperatures.

**Observations on the Behaviour of Sillimanite Mixes on Being Pressed. Part III. Further Experiments on the Variations in Texture at Different Positions in the Pressed Block.** F. H. Clews, W. F. Ford and A. T. Green. (Thirtieth Report of the Refractory Materials Joint Committee: Institution of Gas Engineers, 1939, Communication No. 218, pp. 68-76). In continuation of the investigation of the relation between the pressing operation and the texture of sillimanite mixes, experiments have been carried out on the alteration in grain-size ratios and the variation in permeability at different positions and depths in the pressed block. From the observations made it is concluded that in general there is a decrease in the degree of compactness and of the crushing of the grains as the distance from the face receiving the pressure increases. There is also evidence which indicates that additional crushing may occur in contact with the metal surfaces of the mould, for instance, at the walls and base.

**The Action of Slags on Refractory Materials. Part III. The Action of a Series of Lime-Alumina-Silica-Iron Oxide Slags on an Aluminous Firebrick.** W. Hugill, J. Vyse and A. T. Green. (Thirtieth Report of the Refractory Materials Joint Committee:



Institution of Gas Engineers, 1939, Communication No. 218, pp. 76-83). The behaviour of an aluminous firebrick containing about 55% of alumina and 45% of silica under the action of the following slags was investigated: (a)  $\text{CaO-Al}_2\text{O}_3\text{-SiO}_2$  slag of high lime content; (b) clinker from a gas-producer; (c) mill scale; and (d) various mixtures of (a) and (c). The observations made indicate that iron-free anorthite (lime feldspar) can crystallise out from the reaction products of firebrick and slags containing considerable proportions of iron oxide, and that the lowest melting composition at about  $1080^\circ\text{C}$ . corresponds approximately with the eutectic of anorthite, magnetite and mullite.

**The Viscosity of Slags and Glasses. The Relation between the Viscosity of Slags and Their Attack on Refractory Materials.** J. R. Rait and A. T. Green. (Thirtieth Report of the Refractory Materials Joint Committee: Institution of Gas Engineers, 1939, Communication No. 218, pp. 83-96). The literature on the relation between the viscosity of slags and glasses and their attack on refractories is reviewed and the conclusion is reached that the future study of slagging should include the investigation of: (a) the relationships between the viscosity, composition and temperature of the slags; (b) the solubility of refractory materials in slags; (c) the rates of diffusion of the liquids formed; and (d) the erosion of refractories by slags under controlled conditions.

**High Porosity Sillimanite Bricks. Part II. Some Properties of Fired Sillimanite Mixes Containing Paper Pulp.** F. H. Clews, N. E. Dobbins and A. T. Green. (Thirtieth Report of the Refractory Materials Joint Committee: Institution of Gas Engineers, 1939, Communication No. 218, pp. 97-101). A report is presented of an investigation of the properties of insulating refractory materials prepared by firing sillimanite mixes containing various proportions of paper pulp. It was thought that the fibrous nature of paper might be utilised to give the fine texture required to confer low conductivity at high temperatures. It was found that the experimental materials had the required texture and stability-under-load at  $1350^\circ\text{C}$ ., but suffered from a tendency to crack on firing and also possessed considerable drying shrinkage. These objectionable tendencies were reduced by including porous grog (obtained from the previous trials) in the mixes, but at some sacrifice of stability-under-load.

**Progress Report of Other Work of Interest to Gas Engineers.** (Thirtieth Report of Refractory Materials Joint Committee: Institution of Gas Engineers, 1939, Communication No. 218, pp. 102-104). The Refractory Materials Joint Committee present a report of research work in progress on the following subjects: (a) The action of chlorine and hydrochloric acid on refractory materials; (b) the action of methane on refractory materials; (c) the action of alkalis on refractory materials; and (d) the behaviour of refractory materials in tension at high temperatures.

**The Elasticity of Chrome and Chrome-Magnesite Refractories, with Special Reference to Thermal Shock Resistance.** A. L. Roberts. (Transactions of the British Ceramic Society, 1939, vol. 38, Nov., pp. 602-619). Previous work by J. H. Chesters and T. R. Lynam showed that the thermal-shock resistance of a series of chrome-magnesite refractories (of the 75%-chromite/25%-magnesite type) was closely dependent upon the grading. In the present investigation an examination was made of the behaviour under torsional stress of certain mixtures from this series selected on account of well-marked differences in resistance to thermal shock, in order to ascertain whether such differences could be correlated with differences in elasticity and mechanical strength. Three chromites of different origin (Rhodesian, Indian and Grecian), two commercial chrome-magnesite bricks and a magnesite brick were tested. Of the chromites, the Rhodesian material showed the highest rigidity modulus and maximum shear stress at 20° C. All the chromites were perfectly elastic at low temperatures, but developed plastic properties at 600-700° C.; the plasticity became relatively great at higher temperatures, illustrating the loss of mechanical strength at high temperatures which is characteristic of these materials. The rigidity modulus and ultimate shear strength of the magnesite brick were very high, corresponding with the extreme hardness and strength of this finely-grained brick. Plasticity was found in this material at 1000-1100° C. The rigidity modulus at room temperature of all the chrome-magnesite mixtures and bricks was of the same order, being approximately  $\frac{1}{2}$  to  $\frac{1}{5}$  of that of the chromites and  $\frac{1}{17}$  of that of the magnesite. The chrome-magnesite materials differed strikingly from the chromites and magnesite in showing at all temperatures of testing both elastic and permanent deformation under applied torsional stress. At temperatures up to 800-1000° C. the ability of these materials to yield under stress may have been due to "slip" or relative movement between the particles; at higher temperatures, however, the tendency to yield was greater and was apparently due to the development of high-temperature plasticity. The essential difference between the chrome-magnesite materials of high and of low thermal-shock resistance appeared to be the greater stress-accommodation of the former (*i.e.*, its ability to yield under stress without breaking), since the other factors affecting the resistance to spalling (the thermal expansion and thermal diffusivity) were almost the same. The value of the ratio of maximum shear stress to rigidity modulus is a comparative measure of the tendency to yield, which is considered to be a factor of significance in relation to the thermal-shock resistance of a refractory material. The optimum temperature of testing to be adopted when comparing the thermal-shock resistance of refractories was also considered and that used in the Chesters and Lee test (*i.e.*, 900° C.) was thought to be satisfactory.

**Practical Application of Monolithic Linings in Cupolas.** F. Oldershaw. (Institute of British Foundrymen: Foundry Trade Journal, 1939, vol. 61, Dec. 7, pp. 385-386). The author describes some experiments undertaken to discover the correct technique to employ in the preparation of a monolithic refractory lining for a cupola using a proprietary ganister material. Among other difficulties it had been found that a weakness occurred in some parts of the lining at a point between 5 in. and 7 in. from the face. This was overcome by a method of double lining. In this, the diameter of the lining was allowed to increase by about 4 or 5 in. beyond the original dimension by using only a small amount of patching after each blow. By doing this, the unconverted part, or backing, where rupture had occurred, regained strength by vitrification; on this strong foundation a new lining was rammed inside the old one. This gave, after a few blows, a much stronger lining than had been obtained in the first instance. The author also tenders some advice on drying out new linings and on the improvement of slag notches.

**The Behaviour and Drawbacks of Refractories used in the Production of High-Grade Steels.** A. Zhak. (Stal, 1939, No. 4-5, pp. 50-59). (In Russian). An extensive review is presented of the various types of refractory products (bricks, stoppers, nozzles, mould stools, hot-top mould linings, ladle linings, &c.) and of the service they have given. Silica fireclay, andalusite, carburised fireclay, graphite, magnesite, magnesium silicate (forsterite), fused magnesite and dolomite refractory products are all considered.

**Advantages in the Use of High-Temperature Bonding Mortars.** J. A. Patterson. (Industrial Heating, 1939, vol. 6, Oct., pp. 944-950). After a general introduction dealing mainly with the essential properties of bonding mortars, *viz.*, refractoriness, constancy of volume, bonding strength, chemical resistance and working properties, the author discusses separately "heat-setting" and "air-setting" high-temperature bonding mortars.

## FUEL

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(Continued from pp. 68 A-69 A)

**The Radiation of Furnace Gases.** A. Schack. (Archiv für das Eisenhüttenwesen, 1939, vol. 13, Dec., pp. 241-248). In a mathematical discussion the author develops equations for the calculation of the amount of radiation from gases which, after combustion, are no longer burning or luminous. These equations will give accurate radiation determinations at temperatures exceeding 450° C. The radiation of non-luminous flames is equal to that of the carbon dioxide and steam present on completion of the reaction, other conditions being equal. With luminous gases the hydrocarbons radiate strongly, the carbon monoxide only a little, and the oxygen and nitrogen not at all. When the gas mixture is high in steam and low in carbon dioxide the rate of heat transfer is much higher than when the opposite conditions prevail.

**Water-Tube Boiler Installation at Ebbw Vale Iron and Steel Works.** (Iron and Coal Trades Review, 1939, vol. 139, Dec. 15, pp. 833-836). **Richard Thomas Boiler Plant at Ebbw Vale.** (Engineering and Boiler House Review, 1939, vol. 53, Aug., pp. 82-87). An illustrated description is given of the boiler plant at the Ebbw Vale Works of Richard Thomas and Co., Ltd. The plant consists of three water-tube boilers which can be fired by coke-oven gas, blast-furnace gas or pulverised fuel. The normal working pressure is 375 lb. per sq. in. and the steam temperature is 675° F.

**British Standard Code for Comparative Commercial Tests of Coal or Coke and Appliances in Small Steam-Raising Plants.** (British Standards Institution, No. 878-1939). Having regard to the desirability of encouraging small steam-users to carry out evaporation tests, the British Standards Institution has drawn up this abridged test code in the hope that it will assist them to make such tests on the evaporation and fuel consumption of their plant as will ensure that they are getting the best possible results from the fuel or appliances purchased.

**Sulphur Content of Coal.** D. Brownlie. (Steam Engineer, 1939, vol. 9, Nov., pp. 57-62, 72). The author reviews the results of recent research work in the United States on the effect of combustion on the sulphur in coal.

**The New Coal Washing Processes Employing Suspensions of Dense Media.** H. Verdinne. (Colliery Guardian, 1939, vol. 159, Nov. 10, pp. 667-670; Nov. 17, pp. 711-714; Nov. 24, pp. 747-750; Dec. 1, pp. 787-788). An English translation is presented of



H. Verdinne's article in *Annales des Mines de Belgique*, 1939, vol. 40, No. 2, pp. 431-472 in which the general principles of the use of dense media for washing coal are discussed and a number of plants using dense media are described. See *Journ. I. and S.I.*, 1939, No. II., p. 254 A.

**Assessing the Tar Yield from Producer Coals.** R. A. Mott and C. E. Spooner. (*Fuel in Science and Practice*, 1939, vol. 18, Nov., pp. 325-328). The authors report on work carried out for the Midland Coke Research Committee on the classification of coking coals, in the course of which they devised a test whereby, using simple apparatus, the amount of tar to be expected from a coal when it is gasified in a gas producer can be assessed. The test can be completed in about 45 min. They also explain some formulæ by which the tar yield can be calculated from the hydrogen content of the coal or from the amount of volatile matter and calorific value.

**By-Product Fuels in the Steel Industry.** G. Fox and W. B. Clemmitt. (*Iron and Steel Engineer*, 1939, vol. 16, Nov., pp. 44-55). The authors discuss the applications of blast-furnace gas, coke-oven gas and mixtures of these two gases in a balanced iron and steel works.

**Clean Producer Gas for Industrial Furnace Work.** A. Docking. (*Fuel Economy Review*, 1939, vol. 18, pp. 43-46). The author argues the case for the increased use of producer gas for industrial furnaces in Great Britain.

**Ford Makes Full Use of Instruments on Coke Ovens and Gas Systems.** W. C. Kernahan. (*Blast Furnace and Steel Plant*, 1939, vol. 27, Oct., pp. 1035-1038; *Heat Treating and Forging*, 1939, vol. 25, Oct., pp. 517-521). The author presents an illustrated account of the system employed for the control and distribution of the blast-furnace and coke-oven gases at the River Ronge plant of the Ford Motor Co., where the total production of gas amounts to about 90,000,000 cu. ft. in 24 hr.

## PRODUCTION OF IRON

(Continued from pp. 70 A-75 A)

**The Staveley Coal and Iron Co., Ltd., Chesterfield.** (Colliery Guardian, 1939, vol. 159, Nov. 17, pp. 703-708; Nov. 24, pp. 741-744; Dec. 1, pp. 781-784). An illustrated description is presented of the mines, collieries, ore-preparation plant, blast-furnaces, cupolas and pipe-casting plant of the Staveley Coal and Iron Co., Ltd., Chesterfield. The pipe foundry is of particular interest, as it contains specially designed machinery for casting pipes centrifugally in metal and in sand moulds.

**The Norrland Ironworks.** (Teknisk Tidskrift, 1939, vol. 69, Nov. 25, pp. 533-535). It is stated that a proposal has been put forward in Sweden for the construction of two blast-furnaces at Luleå, a Baltic port in the province of Norrland. Some arguments for and against this proposal are presented and the relative merits of charcoal and coke as reducing agents are discussed.

**"Dry" Furnace Practice.** L. L. Lewis. (American Society of Refrigeration Engineers: Steel, 1939, vol. 105, Nov. 20, pp. 54-58, 82; Nov. 27, pp. 42-46, 78). The author gives a comprehensive description of the dehumidifying plant which the Woodward Iron Co., Woodward, Alabama, has installed for removing the moisture from the blast before it passes to the stoves. He also discusses the costs. A brief account of this plant appeared in Iron Age, 1939, vol. 144, July 20, pp. 38-39 (see Journ. I. and S.I., 1939, No. II., p. 257 A).

**Investigation of the Working of No. 3 Blast-Furnace.** I. Kozlovich. (Stal, 1939, No. 6, pp. 1-7). (In Russian). In this, the concluding part of an account of an investigation of the smelting process in No. 3 blast-furnace at the Zaporozhstal Works (see p. 70 A), the author presents and discusses the experimental data obtained at the third level, the fourth level (7160 mm. above the iron notch) and in the hearth. The level at which the ore is completely reduced was also determined. The zones of slag formation depend on the temperature of the blast as well as on the nature of the ore. Basing his views on the experimental material obtained, the author comes to the conclusion that the furnace diameter of 8 m. is not a limiting size and that the dimensions could be increased to bring the volume up to 1700-1800 cu. m. without loss of efficiency.

**On the Mechanism of the Reduction of Oxides and of Oxide Mixtures, especially of Iron Oxide, with Carbon at High Temperatures.** W. Schaller and E. J. Kohlmeyer. (Metall und Erz, 1939, vol. 36,

Dec. 1, pp. 564-569). The authors observe that, as a rule, investigations of reduction and oxidation equilibria are carried out in temperature ranges in which the oxides and the metals formed are in the solid phase. In the present paper they describe laboratory investigations of the reduction of molten oxides with solid carbon which were carried out in the 1390-1570° C. range. The results showed that the heavy losses observed in the reduction of mixtures of iron oxides is due to the formation of volatile and very unstable iron carbonyls. The volatilisation of one mol of iron requires three mols of carbon or of carbon monoxide and the reaction can take place at 1150° C. The composition of the volatile iron/carbon-monoxide compound is, therefore, assumed to be  $\text{Fe}(\text{CO})_3$ . This radical carbonyl is very unstable and immediately forms  $\text{Fe}_2(\text{CO})_6$ , but this also quickly decomposes, with the result that the end products are iron, iron oxide and carbon monoxide.

**The Effect of Silica, Titania and Alumina on the Viscosity of a Synthetic Acid Slag and the Calculation of the Viscosity of Acid and Basic Blast-Furnace Slags from the Chemical Composition.** K. Endell and G. Brinkmann. (Stahl und Eisen, 1939, vol. 59, Dec. 7, pp. 1319-1321). As an extension to an investigation by Endell and Kley of the viscosity of blast-furnace slags (*see* Journ. I. and S.I., 1939, No. II., p. 133 A), the present authors studied the effect of a considerable increase in the silica, titania and alumina contents of a slag on its viscosity. They found that: (1) An increase in the silica content of an acid slag increased its viscosity; (2) additions of titania up to about 17% decreased the viscosity of the slag used in the experiments; and (3) increasing the alumina content increased the viscosity and also made the slag more brittle. The authors also construct a "viscosity curve" by means of which the viscosity of acid and basic slags at 1400° C. can be calculated from the chemical composition.

**An Attempt to Produce Wrought Iron by the Aston-Byers Process.** L. Ya. Kabanov. (Metallurg, 1939, No. 7, pp. 44-47). (In Russian). After outlining the Aston-Byers process, details of the first experiment with the process at a Russian works are reported. Open-hearth rimming steel was used instead of Bessemer steel, and the slag was melted in a magnesite-lined arc furnace. The steel contained carbon 0.13%, manganese 0.42%, phosphorus 0.03% and sulphur 0.03%. The composition of the iron obtained was: 0.025-0.030% of carbon, traces of manganese, 0.012% of phosphorus and 0.11% of sulphur. It could be readily forged at high temperatures, but became hot-short at 900° C. Its mechanical properties were: tensile strength 32 kg. per sq. mm., yield strength 19 kg. per sq. mm., elongation 39.8%, and reduction in area 72%. In the impact test, the test piece was bent through 90° without completely fracturing.

**The Smelting of Low-Grade Acid Ores by the Krupp-Renn Process at the Full-Scale Test Plant of the Fried. Krupp A.-G.**

H. Lehmkuhler. (Stahl und Eisen, 1939, vol. 59, Nov. 30, pp. 1281-1288). A reproduction of a paper which appeared in Technische Mitteilungen Krupp, Forschungsberichte, 1939, vol. 2, Sept., No. 12, pp. 154-162. (See p. 74 A).

**The Effect of Sintering Time, Temperature and Pressure on the Strength Properties of Sintered Iron.** W. Eilender and R. Schwalbe. (Archiv für das Eisenhüttenwesen, 1939, vol. 13, Dec., pp. 267-272). The authors report on an investigation which had the object of determining whether sintered iron made from powder between 0.075 and 0.5 mm. could be produced in a similar manner to that employed with a more finely ground material, and what effect the time and temperature of sintering, the grain-size and the pressure had upon the tensile properties, density and microstructure of the product. They came to the following conclusions: (1) The sintering of coarse iron powder followed the same laws as that of fine powder; (2) a sudden increase in grain-size took place in both cases when the sintering temperature reached 850-900° C.; and (3) as the sintering temperature was increased there was at first a sudden increase in strength, then a marked decrease in strength and, finally, at high sintering temperatures, another increase in strength.

**General Principles Applicable to the Preparation of Alloys by Fusion.** A. Portevin. (Revue de Métallurgie, Mémoires, 1939, vol. 36, Oct., pp. 429-445). The author discusses the general principles governing the melting and casting of ferrous and non-ferrous alloys for production of alloys of given compositions. The methods are based on: (a) The direct melting of new metals of variable purity; (b) the melting of alloys of the composition desired in the product with allowances for losses by oxidation and other causes; (c) the preparation of parent alloys of different composition from that required in the product; and (d) the addition of elements or alloys after the main portion of the charge has melted. He examines in particular the properties of metals at various temperatures between their melting and boiling points and how these are affected by the composition of the furnace gases and the refractory materials of which the crucible or furnace is made.

**South African Iron and Steel Industry.** (Iron and Coal Trades Review, 1939, vol. 139, Dec. 8, p. 793). The development of the iron and steel industry in South Africa from 1901 to the present time is reviewed and the up-to-date plant of the South African Iron and Steel Corporation is briefly described. This plant now includes a battery of 57 coke-ovens with by-product plant; two blast-furnaces producing 500-600 tons per day each; one 500-ton mixer; three basic open-hearth furnaces (two of 120 tons each and one of 250 tons); heavy and light rolling mills; calcining plant; laboratories and test house.



## FOUNDRY PRACTICE

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(Continued from pp. 76 A–78 A)

**The Cupola and the Melting of Iron.** H. H. Shepherd. (Foundry Trade Journal, 1939, vol. 61, Nov. 30, pp. 367–368). The author comments on Girardet's paper bearing the above title (*see* p. 77 A). He does not believe that the theory that the zone of maximum temperature extends from the tuyere level to a height equal to ten times the average diameter of the pieces of fuel can be applied to all cupolas, although it might well apply to a particular cupola practice. The present author also draws attention to a number of factors which have a bearing on Girardet's statement that the metal left in the well of the cupola will pick up carbon; these factors are: (a) The type and composition of the mixture; (b) the reactivity and size of the coke; (c) the height of the coke-bed and variations in this height; (d) the temperature of the melting zone; and (e) the air volume and pressure.

**Briquettes as a Substitute for Pig-Iron.** (Foundry Trade Journal, 1939, vol. 61, Nov. 23, p. 360). Some particulars are given of the use of briquettes of pressed cast-iron borings and turnings as a material for melting in the cupola. This article also appeared in Iron and Coal Trades Review, 1939, vol. 139, Nov. 10, p. 658 (*see* p. 76 A).

**The Electric Melting Furnace in the Grey-Iron Foundry.** T. Klingenstein and H. Kopp. (Stahl und Eisen, 1939, vol. 59, Nov. 30, pp. 1288–1291). A reproduction of an article which appeared in Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns, 1939, vol. 7, Sept., pp. 147–156. (*See* p. 77 A).

**Alloy Cast Irons.** P. A. Russell. (Proceedings of the Staffordshire Iron and Steel Institute, 1938–39, vol. 54, pp. 72–75). After mentioning some of the characteristics imparted to cast iron by the addition of the alloying elements nickel, chromium, silicon, manganese, copper and molybdenum, the author discusses in more detail the methods of introducing the alloys into the molten metal. He concludes with some notes on the moulding technique for alloy cast irons.

**Melting Malleable Iron in an Electric Furnace.** (Giessereipraxis, 1939, vol. 60, Oct. 8, pp. 401–403). The advantages and disadvantages of using cupolas and electric furnaces for the manufacture of malleable iron at the rate of 7–8 tons per day are considered and the conclusion arrived at is that the former are much more economical than the latter.

**Notes on the Physical Testing of Rammed Moulding Sands with Special Reference to the Specific Compressibility.** W. Reitmeister. (Giesserei, 1939, vol. 26, Dec. 1, pp. 577-584). The author describes some methods of determining the characteristics of moulding sand, including the German Engineering Standard method of measuring the compressibility. He uses the term "specific compressibility" to denote the percentage reduction in volume of 1 kg. of the sand after compression with a force of 500 kg. cm. He also discusses porosity and strength determinations and the relation between these properties, quoting data obtained from tests on some German moulding sands.

**Recent Practical Achievements in the Science of Sand Control and in the Preparation of Moulding Sand.** Dünner. (Giesserei, 1939, vol. 26, Dec. 1, pp. 584-586). The author describes a modern moulding-sand mixer and compares the properties of sand prepared with it with those of sand from an older machine. The compressive and shear strengths and the porosity in relation to the mixing time are compared by a series of graphs.

**Insufficiently Dried Oil-Sand Cores Cause Rejects.** F. Paschke. (Giessereipraxis, 1939, vol. 60, Sept. 10, pp. 379-382). The author describes how the cause of the production of faulty medium weight castings containing cavities was traced at an iron foundry to the incorrect drying procedure used for drying the oil-sand cores. He discusses the effects of using cores containing too much or too little oil and methods of controlling the drying stoves.

**Problems in Pattern-Plate Making.** A. Irvine. (Institute of British Foundrymen: Foundry Trade Journal, 1939, vol. 61, Dec. 14, p. 413). The author describes some methods of dealing with the bending, twisting, springing and blistering which sometimes occur in the making of patterns and pattern plates.

**Modern Permanent Mould Casting.** E. C. Hoenicke. (Iron Age, 1939, vol. 144, Nov. 23, pp. 47-50). The author describes the moulding equipment at an American foundry for the mass production of small grey iron castings. It comprises a revolving platform carrying twelve metal moulds which are cooled by a current of air passing along a separate duct from each mould to a common suction line in the centre. The platform is rotated at any desired speed between 2 and 6 min. per revolution, and it requires only two attendants, one to pour and one to eject the castings. If cored moulds are being used an additional operator is required.

**Proper Provision for the Escape of Air Prevents Rejects.** F. Naumann. (Giessereipraxis, 1939, vol. 60, July 30, pp. 325-330; Aug. 27, pp. 353-356; Sept. 10, pp. 374-377; Sept. 24, pp. 392-395). Various recommendations are made with numerous diagrams illustrating methods of preparing moulds which provide adequate means for the escape of air.

**The Pouring Time for Iron Castings.** B. Osann. (Giessereipraxis, 1939, vol. 60, Sept. 24, pp. 389-395). The author presents

formulae for calculating: (a) The weight of iron which should be poured per second given, the dimensions of the gate of the casting and the height of the ladle spout above the gate, and (b) the correct dimensions of the riser in relation to the velocity of the gases leaving the mould. He gives some examples of their application.

**Running Thin Castings.** G. Henon. (Foundry Trade Journal, 1939, vol. 61, Nov. 23, p. 351). The author describes and illustrates the correct technique for the vertical and horizontal filling of moulds for thin castings.

**Moulding Ship's Propeller Wheels.** M. Wayman. (Institute of British Foundrymen: Foundry Trade Journal, 1939, vol. 61, Nov. 30, p. 369). The author describes the technique employed in the preparation of a mould for casting a ship's propeller weighing about five tons.

**"Rat-tailing" on Flat Castings.** T. R. Goodwin. (Institute of British Foundrymen: Foundry Trade Journal, 1939, vol. 61, Dec. 21, p. 432). The author describes his efforts to trace the cause and find a means of preventing the occurrence of furrows on thin flat castings such as stove tops which are to receive an enamel finish. This defect is known as "rat-tailing" or "worm-marking." The author tried a number of methods of sand preparation and eventually felt justified in assuming that the defect arises from the sand being out of condition due to over-milling or low permeability. At the foundry in question the sand now used with satisfactory results has a green strength of 4.3-4.5 lb. per sq. in. and a permeability of 25.

**Compound Steel for Guillotine Knives.** E. Zotova. (Stal, 1939, No. 6, pp. 40-41). (In Russian). Compound steel is used for long guillotine knife-blades to avoid distortion on quenching. The author describes the experimental production of compound ingots from which this steel strip was obtained. The ingots were cast in open-top moulds; the iron, which should have a carbon content of 0.10-0.15%, being poured into the larger portion of the mould while a low-alloy tool steel is poured, at the same time, through a funnel, into one corner of the mould, which is partitioned off by means of a small steel angle. The preliminary experiments in general gave satisfactory results, a good bond between the iron and the steel being obtained. The knives made from the strip were used in machines for cutting veneer and were found to be as good as the imported ones.

**The Present State of Knowledge of the Viscosity of Liquid Metals and Alloys.** W. Claus and F. Blank. (Metallwirtschaft, 1939, vol. 18, Nov. 17, pp. 917-924; Nov. 24, pp. 938-943). In the first part of their paper the authors present a review, for which completeness is claimed, of investigations on the viscosity of metals and alloys in the liquid state. The first measurements known to be made of the viscosity of a metal were carried out by Warburg on mercury in 1870. Beginning with a description of this investigation by

Warburg, the authors give a chronological account of the development of the measurement of the viscosity of metals up to 1932, when Saito and Matsukawa published an extensive study of the subject. (*See Journ. I. and S.I., 1933, No. I., p. 659 A*). The authors briefly describe the methods and apparatus used by the various investigators for their measurements, which, of course, in most cases had to be carried out at very high temperatures. The second part of the paper consists of extensive tables which are said to contain all the published data of theoretical and practical interest on the viscosity of metals and alloys. Much of this information refers to ferrous alloys.

**Averages Vs. Measured Facts in Foundry Costing.** A. E. Grover. (*Foundry, 1939, vol. 67, Nov., pp. 32-33, 90-92*). The author compares some methods of analysing costs in a foundry and demonstrates that, in the case of a foundry making a variety of castings, a false estimate of the costs will be obtained if the cost of one job is estimated from the average cost per lb. of a number of previous and unrelated jobs instead of being based on the known costs of melting, core-making, moulding and the overhead charges.



## PRODUCTION OF STEEL

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(Continued from pp. 79 A-84 A)

**How to Increase Steel Production.** G. Bulle. (Iron Age, 1939, vol. 144, Nov. 9, pp. 46-48; Nov. 16, pp. 44-46). An abridged English translation is presented of an article which appeared in Stahl und Eisen, 1939, vol. 59, July 13, pp. 809-814 on measures which the author proposes for increasing the production of steel by the Bessemer, open-hearth and electric-furnace processes in Germany. (See Journ. I. and S.I., 1939, No. II., p. 197 A).

**Bessemer Blowing with Constant Pressure at the Wind Box.** S. Chase. (Blast Furnace and Steel Plant, 1939, vol. 27, Oct., pp. 1029-1033). The author considers factors affecting the flow of air through the wind box and tuyeres of a Bessemer converter with particular reference to the shape of the entry of the tuyeres and to the formation of a ring of solidified metal which constricted the orifice of each tuyere. He calls the latter phenomenon "stalagmitic growth," and is of the opinion that this growth progresses during the first third of the total blowing time and that it melts away during the second third. The author also develops equations by which the effect of the stalagmitic growth on the quantity and pressure of the blast can be calculated.

**New Developments in the Design of Open-Hearth Furnaces.** N. Veselkov and G. Cherepakhin. (Stal, 1939, No. 4-5, pp. 21-24). (In Russian). The authors discuss slag removers and suspended furnace roofs. In the case of the former, recent American designs in which liquid slag is continuously drained off are referred to. The authors suggest a similar design in which the liquid slag is drained off into a slag pocket provided with double walls and bottom separated by a layer of sand. This enables the solidified slag to be removed easily. In connection with roofs, the authors outline a special design of suspended roof constructed with Dinas bricks. When first fitted into position provision is made for the expansion of the roof. It is also possible to renew large portions of the roof using bricks impregnated with pitch or soaked in creosote.

**Operation Control by Instruments at a Swedish Acid Open-Hearth Furnace.** S. E. Brundin and J. Paues. (Jernkontorets Annaler, 1939, vol. 123, No. 9, pp. 441-481). (In Swedish). The authors describe the experience gained in the use of various instruments to assist in controlling the working of a 17-ton acid open-hearth furnace at a Swedish steelworks. The instruments used included a manometer connected to the furnace, flowmeters in the air and producer-gas mains, manometers connected to the air and

gas chambers, radiation pyrometers in the air chambers, and iron-constantan thermocouples in the gas mains and in the flue leading to the chimney. In discussing the use of the instruments, the authors state that after careful calibration and testing the instruments required little maintenance and the information they gave assisted greatly in the control of the furnace, and the cost of installing them was therefore fully justified.

**The Working of Blaw-Knox Valves in the Exhaust-Flue System of the No. 6 Open-Hearth Furnace at the Zaporozhstal Works.** M. Savos'kin. (Stal, 1939, No. 4-5, pp. 25-27). (In Russian). The investigation of the efficiency of the Blaw-Knox valves in the flue system of one of the open-hearth furnaces at the Zaporozhstal works showed the valves to be unsatisfactory as they allowed a leakage of gas of 14.0-16.5% which led to a corresponding increase in the consumption of gas.

**Oxygen Content of Steel in the Course of its Production in the Basic Open-Hearth Furnaces by Stakhanovite Methods.** B. V. Stark and E. V. Chelishchev. (Metallurg, 1939, No. 7, pp. 17-31). (In Russian). The extensive investigation described was carried out to settle the question as to whether the intensification of the open-hearth process (with yields of up to 11 tons of metal per sq. m. of hearth) resulted in an increased oxygen content of the steel. The experiments consisted of taking samples of metal and slag at various stages of the process. The carbon, manganese and oxygen contents of the metal samples and the lime, silica, alumina, manganese oxide, magnesium oxide, the ferrous and ferric oxide contents and the viscosity of the slag samples were determined. The Herty method of determining the oxygen content using reduction with aluminium was employed, with the one modification, however, that the aluminium was introduced into the sampling pot, which was one similar to that used by Leiber. The results (plotted against time) showed that the average oxygen content in the heats investigated was 0.020% and in no case did it exceed 0.040%. The oxygen content of the intensified heats tended, if anything, to be lower than in ordinary heats. It is concluded that the rate of carbon elimination is much higher than that of the migration of the ferrous oxide from the slag into the metal. The elimination of carbon was caused mainly by the oxides in the slag and not by the oxides in the metal. The oxygen content of the metal is determined by at least three out of the following four phenomena, which take place simultaneously :

- (1) The migration of ferrous oxide from slag to metal.
- (2)  $C + FeO \longrightarrow Fe + CO$ .
- (3)  $FeO + Mn \longrightarrow Fe + MnO$ .
- (4) Increase in the ferrous oxide content of both metal and slag due to the reaction  $MnO + Fe \longrightarrow FeO + Mn$ .

In conclusion, the results were used to plot a diagram showing the equilibrium between the reversible reactions  $MnO + Fe \rightleftharpoons Mn + FeO$ .

**Control of Sulphur in Basic Open Hearth.** T. L. Joseph and F. W. Scott. (Iron Age, 1939, vol. 144, Nov. 23, pp. 34-36; Nov. 30, pp. 30-34; Dec. 7, pp. 49-53). In the first part of this paper on the control and effect of sulphur in steel the authors present the results of a quantitative analysis of the non-metallic inclusions in a slab and in two sheets rolled from rimming steel ingots, and they relate the occurrence of sulphides to their probable position in the ingots from which the material was rolled. In the second part the authors examine the general relationship of the sulphur in the ladle to that in various parts of the ingot, and its distribution in sheet and strip rolled from different parts of the ingot. Mechanical tests and analyses of steel sheet showed that the amount of sulphur in the centre of a sheet should not exceed 0.040%, and that the maximum sulphur content will be found at the centre of sheets rolled from the top portion of the ingot. Further experiments demonstrated that if the sulphur content of the sheet is to be kept below 0.040%, the sulphur in the ladle must not exceed 0.028%. In this part the authors also study the source of the sulphur in steel and present tables showing how variations in the sulphur content of the coal used in the gas-producer, of the pig-iron and of the gas over the bath affect the amount of sulphur in the steel produced. In the concluding part the authors continue their examination of the distribution of sulphur by examining the amounts present in the molten metal and in the slag as well as the transfer of sulphur from the slag to the furnace gases. They state that in the final analysis the sulphur in the gases determines the amount present in the finished steel.

**Production of Acid-Resisting Steel Y41 Containing Titanium.** V. Speranskiy. (Stal, 1939, No. 4-5, pp. 29-35). (In Russian). Originally the composition of steel Y41 in billets for tube making was: carbon 0.14% max., silicon 1.1% max., manganese 0.2-0.7%, chromium 17.0-20.0%, nickel 8.0-10.0%. The titanium content was calculated by multiplying the carbon content by five and subtracting 0.15. Difficulties experienced in piercing billets led to an investigation of the influence of the various alloying constituents on the plastic properties of the steel. In these investigations, which are discussed, the behaviour during piercing was related to the amount of ferrite present. Additions of both aluminium and titanium are undesirable, as they increase the amount of ferrite, and they should therefore be reduced to a minimum. The amount of titanium to be added can be reduced by reducing the carbon content. The chromium:nickel ratio should not exceed 1:9. The optimum composition finally arrived at was: Carbon 0.12% max., silicon 0.3-0.8%, manganese 0.2-0.7%, sulphur 0.03% max., phosphorus 0.03% max., chromium 17.0-19.0%, nickel 9.0-11.5%, and titanium up to 0.6%. The reduction of the chromium and titanium contents did not affect the resistance to intercrystalline corrosion. After referring to earlier methods of melting, the special

electric-furnace method developed at the Kirov works is described in great detail. The charge is melted down with 2% of lime, and ore is added to oxidise the carbon, which at the end of the boil should be about 0.03–0.04%. The slag is removed, and ground ferro-silicon and then manganese are added and a silica slag is made up. Ferro-chromium is then added, the slag deoxidised and partially removed, after which ferro-titanium is put in, and finally, after adding ferro-silicon to the slag, the metal is heated up and tapped at 1490–1495° C. In teeming, the viscosity of the alloy must be taken into account. In conclusion, the technique of forging and rolling this type of steel is discussed with reference to temperatures, degree of reduction, &c.

**Special Steel.** W. Kossmann. (Stahl und Eisen, 1939, vol. 59, Dec. 14, pp. 1333–1336). On the occasion of the silver jubilee of the Edelstahl-Verband, the author presents a historical survey of the production of special steels in Germany and of the history of the Edelstahl-Verband.

**High-Purity (99.995%) Aluminium or Remelted Aluminium for the Deoxidation of Iron and Steel.** E. Piwowarsky. (Aluminium, 1939, vol. 21, Nov., pp. 744–746). The Arbeitsgemeinschaft deutscher Aluminiumschmelzhütten e.V. supplies two qualities of remelted aluminium containing more than 92% and 90% of aluminium, respectively, which are intended for use as deoxidisers in the steel industry. The maximum amount of deoxidiser used is 0.2% of the weight of the steel treated, so that the quantity of impurities introduced together with the aluminium is minute and has no deleterious influence. This leads to the conclusion that it is uneconomical to use the much more expensive high-purity aluminium as deoxidiser.

**Experience Gained from the Use, during Five Campaigns, of a 1200-Ton Mixer.** I. Chirkov. (Stal, 1939, No. 6, pp. 8–13). (In Russian). The thirteen 200–350-ton open-hearth furnaces of the Kuznetskiy works are served by a 1200-ton-capacity "Bamag" mixer. This has now been in use for almost five years with a throughput of about four million tons of pig-iron. Constructional details are described and the working of the mixer during this time is dealt with. It has been found that effective mixing depends mainly on the volume of iron in the mixer and the time for which it remains in it. Improvements in construction which would prolong the life of the refractory lining, and consequently increase the output capacity per campaign, are suggested.

**Electric Arc Melting Furnace.** P. W. Schlenker. (Brown Boveri Review, 1939, vol. 26, July, pp. 169–172). The author presents an illustrated description of a 3-ton and a 30-ton Brown-Boveri electric-arc furnace for steel making.

**Electric Arc Furnaces with Inclined Walls.** M. Zuev. (Stal, 1939, No. 6, pp. 30–31). (In Russian). The reconstruction of three electric-arc steel-melting furnaces during which the walls of



the outer casing and the internal walls were inclined at an angle of  $9^{\circ}$  had the following results: (a) Improved life of the refractory lining and roof; (b) reduced electrode and energy consumption; and (c) improved quality of the steel because there was no disintegration of the lining.

**The Use of Titanium Concentrate in the Electro-Metallurgy of Steel.** V. M. Zamoruev and B. L. Levina. (Metallurg, 1939, No. 7, pp. 31-43). (In Russian). The possibility of using a titanium ore concentrate (titanium dioxide 45%, silica 7%, ferric oxide 4%, lime 33%) instead of the more expensive ferro-titanium as a source of titanium in the acid and basic electric-furnace melting of plain carbon, low-alloy (chromium-nickel) and 18/8 stainless steels was investigated. The process was found to be successful when melting under basic slags in a basic furnace. There was no appreciable reduction of the titanium dioxide from the concentrate in the acid furnace and in the basic furnace under semi-acid slags, but this question needs further investigation. When reduction of the titanium concentrate did occur, there was a lowering of the nitrogen content of the steel, and in the case of the basic furnace, when melting under basic slags, a certain desulphurising action was also observed. The degree of reduction of the titanium dioxide depended on the amount of metallic oxides in the slag at the time of adding the concentrate. The reduction was primarily due to silicon and aluminium and only to a small extent to the carbon, though a higher carbon content of the metal favoured reduction. Losses of titanium were found to occur when tapping the heats into the ladle.

**Electric Tropenas Furnace for Alloy Steels.** (Iron and Coal Trades Review, 1939, vol. 139, Dec. 1, p. 767; Metallurgia, 1939, vol. 21, Nov., p. 4; Foundry Trade Journal, 1939, vol. 61, Dec. 28, p. 448). A process is described which is very suitable for the manufacture of high-alloy iron or steel. An adaptation of the Tropenas furnace is used. The furnace is rectangular instead of circular in section, and additional heat can be supplied by electrical equipment to bring up the temperature after the addition of the alloys. To do this a section of the furnace on the tuyere side is removed and a replica section carrying the electrodes is lowered into position and the arcs adjusted, the operation occupying a few minutes only. On completion of the heating, the electrical portion is removed, the solid section replaced, and the charge can then be poured. For adding the alloying materials there is a sealed hopper attached to the tuyere box; this contains one or more partitions. Granulated ferro-silicon, manganese, nickel or chromium may be fed into the bath during blowing operations by means of tubes leading into the tuyere orifices; the granules are thus impelled into the molten iron. This patented plant is suitable for producing quantities of from 10 cwt. to 3 tons per hr. either of steel, alloy steels or special high-duty cast irons.

## FORGING, STAMPING AND DRAWING

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(Continued from p. 86 A)

**Determination of the Resistance to Deformation by Dynamic Upsetting and of the Coefficient of External Friction for some Types of Structural Steel.** K. Ginzburg and N. Ul'man. (Stal, 1939, No. 6, pp. 26-28). (In Russian). Three low-alloy chromium-nickel-manganese steels were used in the form of 20 mm.-dia., 35 mm.-high, cylindrical test-pieces machined from normalised rolled stock. They were forged using a tup weighing 52 kg. dropped from 1.5 and 2.5 m., respectively. The forging temperature ranged from 650° to 1050° C. For all the steels at a given temperature the mean dynamic resistance to deformation was higher for the lower speed of deformation and the degree of deformation was less. The resistance to deformation decreased and the degree of deformation increased as the temperature was raised. Using a duralumin test-piece as a standard, the coefficient of external friction of the three steels was determined from the vertical and lateral deformation of cylindrical test-pieces on forging. The coefficient of friction at 1020° C. was found to be 0.3 for all three steels. Using their own results and those of other investigators, the authors show that the formulæ suggested by Ludwig and Prandtl for the relation between resistance to deformation and velocity of deformation are not satisfactory.

**On the Origin of Internal Cracks in High Speed Steel Forgings.** I. D. Pichakhchi and N. V. Tikhomirov. (Metallurg, 1939, No. 7, pp. 75-82). (In Russian). Internal cracks in milling-cutter blanks forged down from square ingots of high-speed steel were due mainly to incorrect forging technique and only rarely to axial porosity of the ingot. Different deformations in different directions during forging cause slipping of the grains which may give rise to cracks during subsequent forging. These causes and the resulting cracks were almost entirely eliminated by adopting a modified forging sequence. Prolonged holding at forging temperatures is also undesirable from the point of view of cracking.

**Tools for Deep-Drawing and Pressing.** J. D. Jevons. (Metal Industry, 1939, vol. 55, Dec. 8, pp. 485-486). Conclusion of a series of articles. (See p. 86 A.) Having surveyed the desirable properties and the heat treatment of tools for deep-drawing and pressing, the author, in this concluding part, discusses how these factors influence the choice of a material for a given tool.

**Fine Wire from Buffalo.** W. A. Phair. (Iron Age, 1939, vol. 144, Nov. 30, pp. 36-39). The author describes the new wire mill at the works of the Wickwire Spencer Steel Co., near Buffalo. At this

mill there are fifteen multi-pass Vaughn drawing machines with which wire 0.003 in. in dia. can be drawn from rods at speeds up to 2200 ft. per min. Another feature of the plant is a flash-baking unit which bakes lime-coated coils of low-carbon steel wire in 5 min. with a forced circulation of air at 500° F.

**The Engineering of Continuous Strand Equipment.** R. R. Tatnall. (Wire and Wire Products, 1939, vol. 14, Oct., pp. 559-563, 609). The author analyses the costs of the different processes which make up that of the manufacture of wire by the continuous process, showing what relation each bears to the whole, and explains some methods of calculating the most economical speeds at which certain processes should be operated.

**Manufacture and Use of Stainless Steel Wire.** S. P. Watkins. (Wire and Wire Products, 1939, vol. 14, Oct., pp. 527-538). In his introduction the author describes the characteristics of the stainless steels most commonly used in wire form, giving attention to their forming, welding and cold-heading properties. He next describes in detail the various stages in the production of stainless-steel wire and presents charts illustrating the effect of cold-reduction on the tensile properties of the various grades. In conclusion he describes and illustrates various applications of the wire.

## ROLLING-MILL PRACTICE

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(Continued from pp. 87 A-88 A)

**Specific Pressures and Spreading in the Hot-Rolling of Steels *EYa-1* and *U-8-A* as Compared with Low-Carbon Steel 1010.** N. I. Svede-Shvets. (Metallurg, 1939, No. 7, pp. 82-89). (In Russian). *EYa-1* is a stainless steel of the 18/8 type, and *U-8-A* is a 0.72% carbon steel, whilst steel 1010 contains 0.04% of carbon. The experiments were carried out on a small two-high mill with rolls 160 mm. in dia. at rolling speeds of 0.6 mm. per sec. Specimens of different widths were rolled at 800°, 900°, 1000°, 1100° and 1200° C. with deformations of 10%, 20% and 30%. It was found that under the conditions of the experiment the spreading was practically independent of the widths of the strips. As the rolling temperature was raised the spreading of the low-carbon steel decreased continuously, although there was a slight increase at a temperature near the  $A_3$  point. The spreading of *U-8-A* and *EYa-1* was practically unaffected by temperature. The spreading of all three steels increased uniformly with deformation. The mean specific pressures increased noticeably with deformation between 10% and 30%, while there was practically no increase above 30% deformation. As the rolling temperature was raised above 800° C. the specific pressures for the *U-8-A* and *EYa-1* steels fell off rapidly, and at temperatures above 1000° C. became lower than those for low-carbon steel.

**Roll Design for Steel Sections.** C. Holzweiler and T. Dahl. (Stahl und Eisen, 1939, vol. 59, Dec. 7, pp. 1313-1318; Dec. 14, pp. 1336-1343). Continuation of a series of articles (see Journ. I. and S.I., 1939, No. II., p. 268 A). The authors continue their mathematical discussion of the design of rolls for producing steel channels, with special reference to the German standard sections NP 300 (old section), 30, 32, 35, 38 and 40.

**Synthetic Materials as Mill Bearings.** C. D. Phillipe. (Midland Metallurgical Societies: Iron and Coal Trades Review, 1939, vol. 139, Dec. 8, pp. 797-798; Metal Industry, 1939, vol. 55, Dec. 15, pp. 503-506; Dec. 22, pp. 529-531). The author describes briefly the process of manufacturing phenol-formaldehyde synthetic resins and laminated material of paper, fabric or cloth impregnated with a solution of the resin in spirit. He next compares the specific gravity, mechanical properties, thermal conductivity and expansion of the laminated material with those of stainless steel, aluminium and magnesium alloys and aircraft spruce. In conclusion he describes the excellent service obtained from synthetic resin bearings in a



mill for cold-rolling stainless steel in which the estimated pressure on the journal neck exceeds 5000 lb. per sq. in.

**Lignostone Bearings for Rolling Mills.** Ya. Gally. (Stal, 1939, No. 4-5, pp. 45-59). (In Russian). Lignostone is made by drying birchwood to a moisture content of 12-14% and then impregnating it under pressure at 80-90° C. with 20% glucose solution. This is followed by several pressings and heat treatments. Finally the glucose with which the wood is impregnated is caramelised by heating the material to 165° C. under a pressure of 80-100 kg. per sq. cm. Lignostone was developed as a substitute for textile-reinforced bakelite for use in rolling-mill bearings. Lignofol (plywood impregnated with bakelite) is another material developed for the same purpose. The physical properties of these two materials are described and the design of bearings, the lubrication and the results of works tests are dealt with. As compared with fabric-reinforced bakelite, lignostone has a much lower loading limit (75 kg. per sq. cm. as compared with 250-300 kg. per sq. cm.); it has a tendency to swell at temperatures above 100° C. Lignofol, on the other hand, is equivalent to fabric-reinforced bakelite, and it is a cheaper material.

**Hot Rolling of Blooms and Slabs.** M. P. Sieger. (Iron and Steel Engineer, 1939, vol. 16, Nov., pp. 20-27). The author describes, with drawings and numerous illustrations, the roughing mills at the Edgar Thomson plant of the Carnegie-Illinois Steel Corporation and at the Middletown plant of the American Rolling Mill Co.

**Ingottless Process of Rolling Molten Steel.** Yu. Grdina and E. Frolov. (Stal, 1939, No. 4-5, pp. 42-44). (In Russian). After brief reference to both Russian and foreign work on direct rolling of liquid molten, an examination of the heat-loss conditions in this type of process leads the authors to the conclusion that it is limited as regards the cross-section of the products which can be produced. Some experiments are described in which an attempt was made to overcome this difficulty by rolling sections using successive pairs of rolls with gradually widening passes, the section being built up by superimposing successive layers of metal which were formed and cooled as the section passed through the different pairs of rolls. The chief difficulty was to obtain a satisfactory welding together of the superimposed layers, particularly in the case of aluminium, with which the first experiments were carried out. The maximum dimensions obtainable were also limited. In conclusion an apparatus for the continuous rolling of molten steel is suggested. In this, metal is poured between four vertical steel strip conveyors which are water-cooled internally. The metal issuing from between the conveyors is passed through rollers.

**New Tube Mill.** (Steel, 1939, vol. 105, Nov. 6, pp. 59-60). A concise description is given of a new continuous tube mill for the Fretz-Moon process at the works of the Republic Steel Corporation. At this mill tubes from 0.5 to 3 in. in dia. in lengths up to 45 ft. are

manufactured. A recuperator-type furnace, 150 ft. long, is used for heating the edges of the skelp prior to welding; this furnace has three heating zones and it is fired by coke-oven gas from burners 9 in. apart.

**"English Electric" Equipment in the Wide-Strip Hot Mill of Messrs. Richard Thomas & Co., Ltd., Ebbw Vale.** H. S. Carnegie. (English Electric Journal, 1939, vol. 9, Oct.-Dec., pp. 204-212). An illustrated description is given of the mill motors and drives at the wide-strip mill at the Ebbw Vale Works of Richard Thomas and Co., Ltd.

**Rectifiers for Steel Mill Auxiliaries.** G. E. Stoltz. (Iron Age, 1939, vol. 144, Nov. 16, pp. 48-51). The author describes a special form of the "Ignitron" mercury-vapour arc rectifier (*see* Journ. I. and S.I., 1939, No. II., p. 343 A), which can be used for efficiently converting high A.C. voltages to 250 V. D.C., for driving the motors of auxiliary machinery in the rolling mill.

**Some Problems of Measurement for the Control of Rolling-Mill Operations.** R. G. Evans. (Fuel Economy Review, 1939, vol. 18, pp. 52-54). The author discusses the efforts now being made and some of the successes achieved in the design of instruments used to control rolling-mill operations. The instruments discussed include: (a) Various kinds of pyrometers for measuring the temperature of furnaces; (b) a device incorporating a photo-electric cell and an amplifying unit with which the temperature of the steel moving through the mill can be indicated and recorded with very little time lag; (c) steam meters for use with steam-driven rolling mills; and (d) instruments for mechanical measurements such as the pressure on the roll necks, the rolling speed and the torque transmitted to the rolls.

**Relay Protective Methods for Steel Mill Service.** H. A. Travers. (Iron and Steel Engineer, 1939, vol. 16, Nov., pp. 36-42). The author describes a number of relay-operated safety devices and electric circuits for use in conjunction with mill motors.

## PYROMETRY

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**Measurement of High Temperatures with Precious Metal Thermocouples.** H. E. Bennett. (Sands, Clays and Minerals, 1939, vol. 3, Autumn issue, pp. 326-330). The author explains the principles of temperature measurement by means of thermocouples and describes the characteristics of rhodium-platinum/platinum, iridium-platinum/platinum and palladium-gold/rhodium-platinum thermocouples. He also considers some factors affecting the selection of suitable alloys for measuring the temperature of molten steel.

**Maintenance of Optical Pyrometers.** M. Baeyertz and J. F. Perkins. (Metal Progress, 1939, vol. 36, Aug., pp. 145-148). The authors describe the instruments and procedure used at the laboratories of the Carnegie-Illinois Steel Corporation for the routine testing and calibration of the disappearing-filament optical pyrometers with which steel temperatures are taken at these works.

**The Application of Optical Pyrometers in Metal and Iron Foundries.** E. R. Thews. (Giessereipraxis, 1939, vol. 60, Dec. 3, pp. 451-454). The author discusses the use of two kinds of pyrometers for measuring the temperatures of molten metals and of furnaces in foundries. These two kinds are the radiation pyrometers or "ardometers" and the disappearing-filament pyrometers. He also makes a number of practical suggestions to ensure that the readings obtained indicate as accurately as possible the true temperature of the molten metal.

**Temperature Control and Its Importance in the Metallurgical Industries.** (Metallurgia, 1939, vol. 21, Nov., pp. 1-3). A number of instruments for the control of electric, gas and oil-fired furnaces are described and illustrated, and a general survey of the various types of regulators available is presented, together with a description of their individual characteristics.

**Automatic Control of Furnace Temperature.** (Foundry Trade Journal, 1939, vol. 61, Oct. 5, pp. 237, 242). Descriptions and illustrations are given of some of the temperature-recording and controlling instruments manufactured by the Cambridge Instrument Co., Ltd. Such instruments are available to control furnace temperatures from 200° C. to 2000° C. In one of these instruments control is adjusted by means of a cam rotating at a speed of one revolution in any period up to 96 hr. The cam can be shaped, if desired, to increase the temperature at any desired rate to an adjustable maximum. Blanks of thin brass are supplied which may be cut according to the control curve required.

## HEAT TREATMENT

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(Continued from pp. 89 A-91 A)

**The Kinetics of Decarburisation of Transformer Steel on Annealing in Hydrogen.** B. D. Averbukh and G. I. Chufarov. (Metallurg, 1939, No. 7, pp. 48-61). (In Russian). A review of earlier work is given by way of introduction. The authors' experiments were carried out with 0.5 and 0.35 mm.-thick specimens of sheets of transformer steel containing silicon 4% and carbon 0.06%. The apparatus used is described. The methane formed was burnt and the carbon dioxide, water and hydrogen sulphide were condensed and determined manometrically. Data obtained for the rate of decarburisation at 600°, 800° and 1000° C. are shown in diagrams. Further experiments showed that the addition of water vapour to the hydrogen slows down the decarburisation considerably owing to the formation of a film of silica or iron silicate which prevents the hydrogen reaching the surface of the metal. The addition of nitrogen also slowed down decarburisation, this being due to the reduction of the partial pressure of the hydrogen. A theoretical discussion of the experimental results leads the authors to the conclusion that decarburisation proceeds by the carbon diffusing to the surface and there reacting with the hydrogen, the rate of decarburisation being controlled by the rate of reaction between the carbon and hydrogen to form methane, and not by the rate of diffusion of the carbon to the surface. For industrial application a temperature of 1000° C. or higher and a rapid stream of hydrogen to remove the methane formed are necessary. Some form of "regeneration" of the hydrogen (removal of methane and other impurities) would be required. Decarburisation with mill-scale is about five times more rapid than with hydrogen, the carbon reacting much more rapidly with the oxygen of the scale than with hydrogen, the latter merely acting as a protective atmosphere.

**Too Big for Flame Hardening?** L. D. Jennings. (Machinist, 1939, vol. 83, Nov. 25, pp. 849-851). The author describes the technique which was adopted to flame-harden the surface of some very large lathe driving-head spools. Each spool consisted of two 10-ton steel forgings bolted together, the assembly measuring 48 in. in length, 51 in. inside dia. and 63 in. outside dia. The spool was mounted in a 120-in. lathe and the heat applied by two water-cooled torches with burner heads 4 in. wide carrying two rows of burner nozzles. Oxygen was supplied from 20 cylinders and acetylene from 18 cylinders connected through two manifolds to a control panel. A series of jets for water-quenching was placed



10 in. behind the torch. The spool was rotated so that the surface passed the torches at 7 in. per min. A depth of hardness of about  $\frac{1}{8}$  in. was obtained and the degree of hardness was fairly uniform between 400 and 450 Brinell.

**Flame-Hardening Methods.** S. Smith. (Steel, 1939, vol. 105, Nov. 13, pp. 66-68). The author describes the equipment used and different techniques for the flame-hardening of steel of different sizes and sections.

**What is New in Heat-Treating Methods, Materials, Processes.** E. F. Davis. (S.A.E. Journal, 1939, vol. 45, Aug., pp. 351-356). The author reviews recent advancements in American heat-treatment furnaces and practice. He refers in particular to the internally-heated Ajax-Hultgren salt-bath furnace in which the salts are fused by pairs of closely-spaced electrodes immersed in the bath itself; this enables pots up to 20 ft. in length to be used as compared with the 6 ft. long externally-heated pots. With regard to gas carburising furnaces up to 35 and 40 ft. in length, he mentions a furnace used by the General Motors Corporation, in which the heavy cost of long alloy-steel muffles is avoided by using a carburising chamber lined with firebrick. This furnace is heated by a series of staggered burners which inject flame into fourteen cylinders 5 ft. long by 1 ft. in dia. connected with flues along the bottom of the furnace. The chamber is heated by radiation from these cylinders.

**Investigation of the Heat Treatment of Chromium and Tungsten Magnet Steels.** V. Erakhtin and K. Margolin. (Stal, 1939, No. 4-5, pp. 63-66). (In Russian). Investigations were made on hot-rolled sheets of chromium magnetic steel *EKh3* (carbon 0.90-1.10%, chromium 2.80-3.80%) and on tungsten steel *EV6* (carbon 0.68-0.78%, tungsten 5.5-6.6%, chromium 0.3-0.5%) in order to settle some of the discrepancies in the temperatures suggested by earlier investigators. The experiments, combined with coercive force and residual induction measurements, showed that both these steels after hot-rolling require a softening heat treatment. Complete parts should be given the following heat treatment: Short period solution heat treatment to dissolve the carbides followed by rapid cooling (from 1030° to 1050° C. for chromium steel, and from 1180° to 1200° C. for tungsten steel); tempering for the precipitation of carbides of an optimum degree of dispersion, and quenching. For the intermediate annealing of chromium steel 30 min. heating at 600° C. is recommended.

**Continuous and Batch Type Bright Annealing Plant at a Sheffield Steelworks.** (British Steelmaker, 1939, vol. 5, Nov., pp. 394-395; Metallurgia, 1939, vol. 20, Oct., pp. 195-196). An illustrated description is given of an electrically heated, continuous, roller-hearth annealing furnace and four vertical cylindrical Grunewald batch-type annealing furnaces at the works of Arthur Lee and Sons, Ltd., Sheffield.

**Generators for Protective Gas from Town Gas and Ammonia.**

G. Simon. (Korrosion und Metallschutz, 1939, vol. 15, Nov.-Dec., pp. 368-369). In recent years continuous annealing furnaces have become very popular and methods had to be developed for the economical production of protective gases suitable for use in continuous furnaces. In practice there are two groups of gas mixtures used for the atmosphere of continuous furnaces, *viz.*: (1) Those produced by partial combustion of town gas or propane, and (2) those produced by cracking ammonia, sometimes with subsequent partial combustion. The methods used for the production of the two groups of protective atmospheres are reviewed with special reference to the various types of apparatus used. The suitable choice, for different purposes, of the composition of the protective atmosphere is discussed.

**Continuous Furnaces with Protective Atmospheres.**

G. Simon. (Korrosion und Metallschutz, 1939, vol. 15, Nov.-Dec., pp. 371-374). The author briefly describes the main types of continuous electric furnaces used in Germany for annealing in protective atmospheres.

**Annealing in a Protective Atmosphere.**

W. Baukloh. (Korrosion und Metallschutz, 1939, vol. 15, Nov.-Dec., pp. 357-367). The author defines the conditions which, in different cases of annealing, have to be fulfilled by a protective atmosphere, and he discusses the effect of the presence of oxygen, water vapour, air, sulphur dioxide, carbon dioxide, carbon monoxide, hydrogen and nitrogen, and of certain mixtures of these gases on the annealing process. He then reviews and briefly describes the technical production of the protective gases and gas mixtures used in practice. Some of these have to be purified and subjected to oxidising or cracking treatment before use. They include producer gas, coke-oven gas, blast-furnace gas, natural gas, methane, propane and butane. Particular reference is made to the preparation and application of "Elektrolen" (cracked town gas). The paper contains also a brief chapter dealing with protective gases for the annealing of non-ferrous metals.

**The Annealing of Tool Steels.**

I. Golikov. (Stal, 1939, No. 6, pp. 32-39). (In Russian). The author makes a detailed examination of the annealing treatment for tool steels and considers the conditions under which it is carried out. In view of the importance of the original structure in deciding the annealing schedule, he lists the structures generally present in standard Russian alloy tool steels after hot working. In considering the  $Ac_1$  transformation, particular reference is made to the behaviour of the carbides and to the form of the residual dispersed carbides. Taking all the available data, the author amplifies the statement originally made by N. T. Belaiew that the formation of lamellar pearlite must be preceded by the complete solution of the cementite on heating by the statement that a pre-requisite for the crystallisation of granular carbide during the pearlite transformation is the presence in the bulk of the original

austenite of regions of residual dispersed carbide. In connection with the effect of annealing temperature, it is pointed out that if annealing is required to produce granular pearlite, then for any given steel the annealing temperature should be between that at which the  $Ac_1$  transformation is complete and that above which the first regions of lamellar pearlite are formed. The deciding factor in obtaining a given structure of the pearlite is the state of the austenite before the cooling of the steel. The rate of cooling, while it affects the hardness, has little influence on the structure of the pearlite. Finally, some reference is made to annealing practice at the Elektrostal works.

**The Heat Treatment of Wire and Wire Products—Electric Furnaces for Wire and Strip.** (Wire Industry, 1939, vol. 6, Nov., pp. 699–704). Continuation of a series of articles (*see* Journ. I. and S.I., 1939, No. II., p. 210 A). A number of small electric heat-treatment furnaces of the continuous and batch type are described and illustrated. They are used for annealing wire, hardening springs and bright annealing small parts.

**Induction Heating.** (Steel, 1939, vol. 105, Nov. 27, pp. 54–56). A description is given of a method of hardening the inner surfaces of cylindrical bodies such as cylinders, sleeves, bearings and hubs. The principle of electrical induction is employed to supply the heat, which is done in a few seconds, and the article is then quenched by a water spray. The machine described is used for hardening pieces 2–7½ in. inside dia., up to 2 ft. long, and it is claimed that the depth and degree of hardness can be controlled with great accuracy. (An abridged account of this process appeared in Iron Age, 1939, vol. 144, Nov. 30, p. 40).

**Quenching of 5KhNM Steel with Minimum Distortion.** T. Nazarova. (Stal, 1939, No. 6, pp. 41–44). (In Russian). The steel studied had the composition carbon 0.61%, silicon 0.36%, sulphur 0.011%, manganese 0.51%, chromium 0.77%, molybdenum 0.21% and nickel 1.48%. It is used for stamping dies. In the first part of the investigation the S-curve of the steel was determined using magnetometric and hardness measurements and microscopic analysis, the temperature range covered being 200–700° C. Decomposition of the austenite was complete in 45 min. at 450° C., a hardness of Rockwell C24 being obtained. To avoid thermal stresses in quenching, the technique of stepped quenching which made use of the prolonged stability of the austenite at 700° C. and between 525° C. and 550° C., was applied. In conclusion, the effect of five different methods of quenching from 830° C. on the internal stresses, hardness and impact strength was investigated.

## WELDING AND CUTTING

(Continued from pp. 92 A-93 A)

**A Study of Heat Effects in Welding.** W. A. Pearl. (Welding Journal, 1939, vol. 18, Oct., pp. 609-614). The author examines the effects of the heat applied during welding on the structure of the weld metal and of the parent metal in the heat-affected zone, and illustrates these structures with numerous macrographs of joints in carbon and alloy steels and in cast iron.

**Reactions in Arc Welding.** R. D. Thomas, jun., and F. H. Rhodes. (Welding Journal, 1939, vol. 18, Oct., pp. 335-S-338-S). The authors investigated the effect of varying the graphite content of the coating of a welding electrode on the properties of the weld produced. They found that: (a) An increase in the graphite content normally resulted in an increase in the carbon content of the deposited metal; (b) when the welding rod was very low in carbon and the coating high in graphite, oxide inclusions occurred in the deposited metal; (c) as the graphite in the coating was increased more silicon was carried into the weld metal; (d) the manganese content of the weld metal increased slightly with increased graphite in the coating.

**Arc Welding Electrodes and Their Relation to the Weld Metal.** W. H. Simon. (Transactions of the Institute of Welding, 1939, vol. 2, Oct., pp. 205-209). The author describes and discusses methods of designing coated electrodes for electric welding and presents equations which relate the analysis of the coating and the weight of metal in the electrode to the composition and weight of the metal deposited.

**Transfer of Electrode Constituents in the Electric Arc.** W. H. Simon. (Welding Industry, 1939, vol. 7, Dec., pp. 399-402). The author discusses the conditions of welding which affect the efficiency factors of the electrode constituents in the arc welding of mild steel. The efficiency factor is the percentage of a constituent of the electrode which is actually introduced into the weld.

**The Effect of Alloying in Metallic Arc Welding.** R. W. Emerson. (Welding Journal, 1939, vol. 18, Oct., pp. 381-S-392-S). The author points out and discusses some of the problems involved in the welding of high-alloy and low-carbon steels. He used many combinations of base metals and electrodes. The results he obtained showed that: (1) Low-carbon and high-alloy stable austenitic steels were not adversely affected as to physical properties by the welding heat, and little difficulty was encountered in welding provided the analysis of the electrode was approximately the same as that of the base metal. (2) When welding low-carbon or a low-alloy steel (one with 0.5-4.0% of the special element) with austenitic



electrodes, it was best to use an electrode in which the austenite was sufficiently stable, so that, after dilution with the low-carbon or low-alloy steel, it would remain as stable austenite and not revert to martensite. (3) A narrow band of martensite is not formed along the fusion line of a weld made with an austenitic steel electrode and a low-carbon or low-alloy steel; each layer of deposited weld metal is entirely austenitic, or else the dilution is sufficient to cause reversion of the entire layer to martensite. (4) In general, any ferrous alloy which has sufficient alloying elements present to cause the steel to be in a stable austenitic state can be satisfactorily welded with an electrode of stable austenite such as the 18/8 or 25/12 type of stainless steel. (5) Satisfactory welds can be made on 17% and 27% chromium iron with either 18/8 or 25/12 stainless-steel electrodes. (6) 12% chromium steel can be successfully welded with either 18/8 stainless steel electrodes or 4-6% chromium steel electrodes. (7) A 17% chromium steel electrode is not suitable for welding either 25/12 or 18/8 stainless steel.

**Further Studies of the Spot Welding of Low Carbon and Stainless Steels.** W. F. Hess and R. A. Wyant. (Welding Journal, 1939, vol. 18, Oct., pp. 348-S-354-S). In this paper the results are presented of tests made on spot welds in hot-rolled, annealed and pickled low-carbon steel 0.047 in. thick and in annealed 18/8 stainless steel 0.068 in. thick. The work is a continuation of that previously reported (*see* Journ. I. and S.I., 1939, No. I., p. 104 A). In general the conclusions reached regarding lighter gauge material are confirmed for the thicknesses now discussed. In the present investigation the authors found that: (1) The diameters of the best welds in the 0.047-in. mild-steel approached very closely to that of the electrode tips; (2) the diameters of the strongest welds in the 0.068-in. stainless steel were about 8% larger in diameter than the electrode tips; (3) the securing of good fusion was of paramount importance; (4) too low a current produced a brittle weld; and (5) the energy input could readily be calculated from electrical resistance measurements between sheet and sheet and between electrode and sheet.

**Strip Welding Practice.** J. H. Cooper. (Steel, 1939, vol. 105, Nov. 6, pp. 46-50). The author examines the factors affecting the hardness of flash-welded joints in steel strip with reference to the importance of reducing the difference between the hardness of the joint and that of the strip when the material has to undergo subsequent cold-rolling. He states that differences in hardness of not more than 15 points on the Rockwell C scale can be achieved by reducing the welding current and the flashing time.

**An Investigation of the Spot Welding of Automobile Grade Mild Steel.** W. F. Hess and R. A. Wyant. (Welding Journal, 1939, vol. 18, Oct., pp. 329-S-335-S). The authors report on an investigation of the optimum conditions for the spot welding of low-carbon steel sheet 0.036 in. thick, cold-rolled and annealed, for the

manufacture of automobile bodies by pressing. They came to the following conclusions: (1) Single-spot lap welds with a shear strength of 1100 lb. per sq. in. could be produced using flat electrode tips  $\frac{1}{4} \times \frac{1}{4}$  in. and 15,000 lb. per sq. in. pressure; (2) the optimum pressure using flat tips was about 15,000 lb. per sq. in.; (3) when applying six cycles of current for a weld the optimum current value under conditions as in (1) and (2) was 12,500 amp., and for twelve cycles it was 11,000 amp.; (4) using dome-shaped tips with a 4-in. radius, six cycles, 11,500 amp. and 750 lb. per sq. in. electrode pressure, the welds had a shear strength 5% less than that obtained when using  $\frac{1}{4}$ -in. flat tips; and (5) spot welds in sheet of fine-grained steel were about 10% stronger than those in the coarse-grained steel which were examined.

**Burning During Welding of Mild Steel Sheet.** T. Swinden and H. Sutton. (Transactions of the Institute of Welding, 1939, vol. 2, Oct., pp. 187-189). The paper prepared for presentation at the Oxy-Acetylene Convention in London in September 1939 is reproduced. (See p. 25 A).

**Welding Galvanized by a New Method.** A. R. Eckberg. (Metal Progress, 1939, vol. 36, Nov., pp. 633-635). It has been found that in the electric welding of galvanised sheet a narrow band of unprotected steel parallel to the line of the weld is left. In the present paper the author describes a technique of welding in which a carbon electrode and a tin-coated copper-silicon filler rod are used. After welding in the manner described it is found that the tin covers the area which was left bare by the other processes. The approximate analysis of the filler rod is: silicon 2.5%, manganese 1.5% and copper 96%. This technique has been patented and is known as the Gaylord process.

**Welding of Boiler Drums and Pressure Vessels.** R. T. Kernoll. (Welding Journal, 1939, vol. 18, Oct., pp. 603-604). The author discusses and compares some of the codes and specifications recognised in the United States for the welding of boiler drums and pressure vessels.

**Boiler Advances.** (Steel, 1939, vol. 105, Nov. 27, pp. 64-68). A brief description is given of the rolling and welding procedure adopted at the works of Babcock and Wilcox Co., Barberton, Ohio, in the fabricating of high-pressure boiler tubes and drums.

**Locomotive Welding Repairs: Main Frames.** W. B. Jones. (Welding Industry, 1939, vol. 7, Dec., pp. 407-410). The author outlines the procedure for the repair and maintenance of locomotive frames by electric welding.

**Welding Heavy Presses.** L. J. McDonough and J. R. Henry. (Welding Journal, 1939, vol. 18, Oct., pp. 614-619). The author discusses some problems in the design of heavy pressing machinery constructed by welding, and in a comparison of cast and welded steel presses he shows that great savings in both weight and cost can be effected by welding.

**Repairs to Steel Castings and other Steel-Mill Parts.** S. D. Baumer. (Welding Journal, 1939, vol. 18, Oct., pp. 619-622). In discussing how thermit, electric and oxy-acetylene welding can be applied to problems of maintenance in a rolling mill, the author first describes how a fracture in a 36-in.-dia. plate-bending roll was repaired by the thermit process, and then describes some repairs to mill-housing castings and pressure cylinders by electric welding. As examples of oxy-acetylene cutting and welding he quotes the reconditioning of a crane runway over a mill building 625 feet long, in which all the joints were scarfed with the cutting torch and then ground and welded.

**Weld Hardening of Carbon and of Alloy Steels.** H. J. French and T. N. Armstrong. (Welding Journal, 1939, vol. 18, Oct., pp. 339-S-347-S). The authors report on an examination of the hardness produced in specimens of carbon- and alloy-steel plate 9 in.  $\times$  6 in.  $\times$  1 in. by depositing a bead of weld metal down the centre of one face. Sections were cut across the weld metal and hardness surveys and tensile tests were carried out. The effects of varying the welding technique on the different kinds of steel is discussed and shown in numerous tables and graphs.

**Weldability Tests.** D. S  f  rian. (Bulletin de la Soci  t   des Ing  nieurs Soudeurs, 1939, vol. 10, Apr.-July, pp. 3465-3477). The author reviews some of the French, Belgian, German and British methods of testing the weldability of steel. The tests he describes fall into two classes: those on free specimens in which the movements caused by expansion and contraction are not restricted, and those on fixed specimens in which the expansion and contraction are artificially restricted, thus setting up stresses in the welded specimen which may cause cracks. In the latter category are the Krupp, Zeyen, Gerbeaux, M  ller and Kommerell methods of testing.

**Forges and the Weldability of Steel.** J. Bernard. (Bulletin de la Soci  t   des Ing  nieurs Soudeurs, 1939, vol. 10, Apr.-July, pp. 3478-3489). After examining some of the properties of structural steel for riveting which are specified in France by the Marine, Bridges and Highways, and State Railway Departments, the author refers to the vagueness of the specification for steel for welding which gives the minimum tensile strength and includes the clause "the base metal must be weldable and be able to withstand the local heat of welding." He then considers some tests which have been devised by French steelworks to test the weldability of steel before despatch to their customers. One such test consists of depositing a bead of weld metal in a copper-coated groove 15 mm. wide in a 12-mm.-thick specimen of the plate to be tested. The welding is purposely carried out under bad conditions using too high an amperage. A strip consisting of the bead and the parent metal under it is then cut from the plate, and from this a specimen is prepared by machining off the deposited metal, and this is sub-

jected to mechanical tests the results of which are compared with those obtained from specimens of the plate unaffected by welding. In order to comply with this weldability test the differences in the values of the elastic limit, tensile strength and elongation must not be greater than 15%, 15% and 20%, respectively. He also gives particulars of a semi-hard weldable steel known as "Supersoudal" developed by the Aciéries de Longwy.

**A Critical Examination of Methods of Testing Welds.** J. M. Willey. (Welding Industry, 1939, vol. 7, Nov., pp. 361-365). The author discusses, with numerous examples from a long experience, errors which are made in the testing of welds. He finds these fall into three groups: (a) Incorrectly shaped test specimens; (b) errors in the mode of execution of the tests; and (c) errors in the interpretation of the test results.

**Endurance Tests on Special Joints with Heat-Treated or Machined Welds.** H. O'Neill and F. C. Johansen. (Transactions of the Institute of Welding, 1939, vol. 2, Oct., pp. 222-225). The authors describe an investigation which had as its object the determination of the change in resistance to reversed stresses at room temperature of a 2-row, riveted, lap joint in 2%-nickel steel after: (a) Applying a sealing run of weld metal, (b) tempering this sealing run with an oxy-acetylene flame, or (c) grinding the surface of the weld fillet. From the data obtained the authors conclude that: (1) Local heat treatment with the oxy-acetylene flame of hard fillet welds in a combined riveted and welded joint in 2%-nickel steel causes a decrease in the fatigue strength of the joint; and (2) surface grinding of the weld metal to produce a smooth and well-shaped fillet improves the fatigue strength.

**Experiences with X-Rayed High-Pressure Pipes and Their Safety Factors.** M. Roš and E. Brandenberger. (Eidgenössische Materialprüfungs- und Versuchsanstalt für Industrie, Bauwesen und Gewerbe, Zürich, 1939, Report No. 122). In the first part of this paper the authors survey the experience gained during the years 1935-1937 in the X-ray testing of welded joints in high-pressure pipe-lines. They report that a definite improvement in the quality of the welded joints has taken place, and state that it is unnecessary to submit the entire length of the seam to X-ray examination in order to prove that a joint is satisfactory provided that proper attention has been paid to correct assembly before welding, the selection of the electrodes, the amperage employed and to the supervision of the operator. The authors point out that other means of testing must not be neglected just because the rather expensive X-ray technique has been employed. In the second part they present the results of microscopic examinations, and tensile, elongation, fatigue, bend and impact tests on specimens cut from pipes welded both in the workshop and in the field.



## CLEANING AND PICKLING OF METALS

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(Continued from p. 28 A)

**Flame Descaling and Flame Cleaning and Dehydrating.** J. G. Magrath. (Welding Journal, 1939, vol. 18, Oct., pp. 588-591). The author describes a form of oxy-acetylene "brush" for descaling steel billets, bars and plates. The "brush" consists of a row of burner nozzles mounted on a small two-wheeled carriage the long handle of which consists of the pipes supplying the oxygen and acetylene. This appliance is pushed across the surface of the steel at 10-20 ft. per min., and the intense momentary heat cracks off any scale and removes any moisture which may be present.

**Metal Cleaning by Washing Machine.** C. C. Hermann and R. W. Mitchell. (Iron Age, 1939, vol. 144, Oct. 12, pp. 26-29). The authors describe a number of continuous washing and degreasing machines suitable for the rapid cleaning of metal parts after the final machining process.

**Electric Cleaning of Metals.** C. C. Hermann and R. W. Mitchell. (Iron Age, 1939, vol. 144, Nov. 23, pp. 42-45). The author discusses the electrolytic process of pickling for the removal of scale from heat-treated machine parts and gives particulars of the composition of the solutions used, the current densities and the equipment required.

**Some Notes on the Practice of Electrolytic Descaling.** H. Prelinger. (Korrosion und Metallschutz, 1939, vol. 15, Nov.-Dec., pp. 374-380). The author reviews some of the more important processes of cathodic and anodic descaling, and gives an account of his investigations on the relation between the current density applied and the time required for cathodic descaling. The results indicate that current densities of 300-1000 amp. per sq. m. are most favourable.

**Submerged Heat by Submerged Combustion.** W. G. See. (Wire and Wire Products, 1939, vol. 14, Oct., pp. 553-555, 615). The author discusses the costs of pickling coils of wire and bundles of rod in acid baths heated by means of burners and combustion tubes submerged in the bath itself. He compares the cost of heating by "submerged combustion" with that of heating with jets of steam.

**Inhibitors in Steel Pickling.** C. P. Weise. (Bulletin of the American Ceramic Society, 1939, vol. 18, Oct., pp. 356-358). The author discusses the character of oxide scale on steel sheet, the reactions in the pickling process and the action of inhibitors. He describes a method of inhibitor-controlled pickling which produces a satisfactory etch and good adherence for enamel.

## COATING OF METALS

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(Continued from pp. 29 A-36 A)

**pH Papers.** P. Frank. (Steel, 1939, vol. 105, Nov. 6, pp. 53, 80). The author describes a new and simple form of pH indicator now available in the United States for testing metal-plating baths. The indicator consists of a strip of impregnated paper which is dipped for a few seconds into the solution to be tested. On the paper there are six fixed colours with the pH value opposite each; this forms a measuring scale with a range of 1.5 pH in stages of 0.3. There is also a sensitive area on the strip with which the solution reacts, changing its colour in accordance with the hydrogen-ion concentration. The colour of the sensitive area is compared with the others and the pH value is instantly seen opposite the corresponding colour. A wide range of strips is available, so that the whole of the pH scale is covered.

**Production from the Gaseous or Vapour Phase of Metallic or Metalloid Protective Coatings.** W. Machu. (Korrosion und Metallschutz, 1939, vol. 15, Nov.-Dec., pp. 387-394). The author discusses two possibilities for the production, from the gaseous phase, of metallic coatings on metallic or non-metallic materials. These processes comprise either the evaporation of the metal required for the coating, with subsequent condensation, or the evaporation of certain of its compounds with subsequent decomposition on the surface to be protected. These processes are not yet used in practice, but the author discusses possible technical advantages of their application. He finally gives an extensive review of patents dealing with the subject.

**Investigations Carried out in the U.S.S.R. on Metallic Coatings and the Electrochemical Protection of Metals.** M. von Pohl. (Korrosion und Metallschutz, 1939, vol. 15, Nov.-Dec., pp. 403-404). The author enumerates twenty-two problems in connection with metallic coatings and other electrochemical means of protecting metals, and gives information as to the scientific Institutes and industrial laboratories in Russia where these problems are being investigated.

**Microscopic and Drop Test Methods on Metallic Electrodeposits.** J. W. Higgins. (Bulletin of the American Society for Testing Materials, 1939, Oct., pp. 21-24). The author describes a microscope with a micrometer eye-piece and the technique of cleaning and etching specimens of plated metal prior to determining the thickness of the coating. He also describes S. G. Clark's jet test, and a drop test used for chromium plating. In the latter, a drop of

concentrated hydrochloric acid is allowed to fall on a restricted area of the plating, and the time taken from the beginning to the end of the gas evolution is a measure of the thickness of the coating.

**Dropping Tests for Measuring the Thickness of Zinc and Cadmium Coatings on Steel.** A. Brenner. (Journal of Research of the National Bureau of Standards, 1939, vol. 23, Sept., pp. 387-403). The author examines the dropping test devised by S. G. Clarke for the determination of the thickness of coatings on steel and makes recommendations regarding its application to zinc and cadmium coatings. This paper has appeared previously in the Proceedings of the American Electro-Platers' Society, 1939, pp. 204-208 (*see* p. 30 A).

**Varied Applications of Thickness Gages for Thin Nonmagnetic Layers.** M. A. Rusher. (General Electric Review, 1939, vol. 42, Nov., pp. 486-487). The author describes and illustrates a portable electrical instrument for measuring the thickness of non-magnetic coatings on steel. The instrument comprises a Wheatstone bridge circuit with one coil in the gauge head which is applied to the coating to be measured, and a balancing coil in the case of the indicating instrument. The former coil is wound on an iron core with a flange on each end, the edges of which are placed on the surface to be measured. The instrument can be used on curved as well as on flat surfaces.

**Ekko Process of Electroforming.** (Iron Age, 1939, vol. 144, Oct. 5, pp. 38-39). Brief particulars are given of a process developed by the United States Rubber Co., Detroit, for making intricate moulds. The process is a particular application of electro-plating by which a coating of iron up to  $\frac{1}{2}$  in. thick can be deposited on a pattern. If the surface is made conductive by dusting with powdered graphite, then wood, glass, plastics or similar materials can be used as patterns; metals can also be used, with the exception of zinc and aluminium. On the completion of the plating process, the pattern is removed, leaving a cavity which is an exact reproduction of the pattern. The electrolytic iron of which the mould is made by this process is said to be of 99.98% purity with a Brinell hardness of 240. If desired, the pattern can be plated first with nickel before putting it in the iron-plating bath, thus producing a nickel lining in the finished mould. No particulars of the iron-plating solution are given, but it is stated that the average current density is about 100 amp. per sq. ft.

**Close Temperature Control in Chromium Plating.** M. H. Gerhard. (Metals and Alloys, 1939, vol. 10, Sept., pp. 280-281). The author reports on the results obtained after changing from steam heating to electric-immersion heating for a chromium-plating bath. The thermostatic control with the electric heating enabled the proper temperature of 108° F. to be maintained within  $\pm 2^\circ$  F., and this fact alone enabled an excellent and consistent quality of plating to be produced.

**Saving of Material in the Production of Nickel Deposits.** E. Werner. (Korrosion und Metallschutz, 1939, vol. 15, Nov.-Dec., pp. 400-403). The author discusses the influence of the composition and pH value of the electrolyte in nickel-plating baths on the optimum utilisation of the nickel content of the anode.

**The Porosity of Nickel, Copper and Chromium Coatings Produced for Protection and Decoration.** V. P. Sacchi. (Korrosion und Metallschutz, 1939, vol. 15, Nov.-Dec., pp. 394-400). The total porosity of an electrolytic deposit is obtained from the specific and the induced porosities. The former is that dependent on the interstices between the crystals of the deposit, and is thus a function of the shape, arrangement and dimensions of crystals comprising the deposit. The latter is produced by pitting, crack formation, unsuitable condition of the surface to be coated, &c. The author discusses the possibilities of reducing these two types of porosity in nickel, copper and chromium deposits.

**Aluminium as Surface Protection for Steel.** H. Hoff. (Aluminium, 1939, vol. 21, Nov., pp. 755-759). Aluminium coatings on steel have proved very effective in the prevention of corrosion in air. The coatings have, however, some disadvantages. They are expensive and difficult to produce, and the coated articles cannot be welded and soldered easily. Various methods for the production of aluminium coatings are reviewed. Of particular importance are the processes in which steel is coated with aluminium foil by hot or cold rolling, and those in which the aluminium surface layer is produced by dipping the steel into molten aluminium under hydrogen or under an inert atmosphere. These latter processes and hot-rolling may lead to the formation of an undesirable brittle intermediate layer of  $\text{FeAl}_3$ , and various means are discussed by which the formation of this intermediate layer can be prevented. The possibilities of the application of aluminium-coated steel, in particular in the canning industry, are reviewed briefly.

**New Coating Offers Unusual Corrosion Resistance.** (Steel, 1939, vol. 105, Oct. 23, pp. 42-43). Some examples are given of the applications of "Corronite-coated" steel. The composition of the coating is not stated, but it can be applied in electrolytic plating tanks. It is claimed to have a high ductility, so that its protective value is unimpaired by bending and drawing.

**Stainless Clad Steel by a Unique Process.** (Metals and Alloys, 1939, vol. 10, Sept., pp. 287-289). A description is given of a process by which stainless steel sheets can be attached to carbon steel plates, the entire area being welded by a continuous electric process. The method and some of the applications of the protected steel plates were described in Steel, 1939, vol. 105, Oct. 2, pp. 42-43, 63-64. (See p. 33 A).

**Hot Galvanizing.** A. T. Baldwin. (Iron Age, 1939, vol. 144, Oct. 26, pp. 23-27, 91). In this description of the hot-galvanising process the author stresses the importance of thorough rinsing



immediately after the material is withdrawn from the pickling bath. He also describes the preparation of a flux bath of zinc ammonium-chloride the use of which improves the adherence of the zinc coating.

**The Reaction of Zinc and Iron in Hot-Galvanizing.** H. Bablik. (Iron and Steel, 1939, vol. 13, Oct., pp. 2-6; Nov., pp. 46-49). After a brief consideration of the zinc-iron system and a study of a series of micrographs of the boundary layers of a galvanised-iron sheet, the author traces the relation between the layer and the phases of the equilibrium diagram. By means of additional micrographs he demonstrates the effects of different dipping times and bath temperatures on the thickness of the boundary layers which are distinguishable under the microscope.

**The Character of the Attack of Zinc on Steel in Hot-Galvanising.** W. Rädiker and R. Haarmann. (Stahl und Eisen, 1939, vol. 59, Nov. 9, pp. 1217-1227). The authors discuss observations made on zinc-iron reactions in the laboratory and during full-scale operation of the hot-galvanising process. They examine in particular the factors affecting the attack of molten zinc on steel which causes : (a) Flaking of the steel ; (b) pitting ; and (c) destruction of the grain boundaries.

**Laboratory and Shop Performance of Non-Reboiling Enameling Sheets.** J. C. Eckel. (Bulletin of the American Ceramic Society, 1939, vol. 18, Oct., pp. 358-360). The majority of steel sheets with a ground coat of enamel refired at 1520-1540° F. for 40-50 sec. and then cooled show some degree of reboiling. The author describes a number of laboratory tests which had the object of determining the influence of the type of ground coat, the rolling and heat treatment of the sheet, and the firing temperature upon the occurrence of this phenomenon.

**Recommended Method of Testing the Acid Resistance of Vitreous Enamel.** (Institute of Vitreous Enamellers, Annual Meeting, Nov. 1939 : Foundry Trade Journal, 1939, vol. 61, Dec. 7, pp. 395-397). This is an interim report by the Chemical Resistance Test Sub-Committee appointed by the Joint Committee of the Institute of Vitreous Enamellers and the British Cast Iron Research Association. In the present report details are given of the sequence of thought and experiment that led to the devising of the recommended test in its present form, together with a description of the test itself. This test gives a quantitative value for the degree of attack of a hot solution of oxalic acid on an enamel surface, expressed as the amount of material dissolved by the acid under standard conditions.

## PROPERTIES AND TESTS

(Continued from pp. 95 A-102 A)

**The Time Factor in the Tensile Testing of Austenitic Steels.** (Metallurgist, 1939, vol. 12, Dec., pp. 80-82). The results obtained in recent years by English, German and Italian investigators on the influence of the rate of increase of load on the results of tensile tests are reviewed. In general it has been found that not only the elastic limit and the yield point, but also the ultimate stress, the elongation and the reduction of area are all increased in different proportions by increasing the rate of application of the load. The effect of time in tensile testing is dependent on the strain-age-hardening properties of the material. The results obtained when testing certain austenitic steels known to be much more susceptible to strain-age-hardening than ordinary carbon steels are therefore of particular interest.

**Stresses in Spindles and Intermediate Couplings of Rolling Mills.** M. Vratskiy and I. Rudyy. (Stal, 1939, No. 6, pp. 14-25). (In Russian). The torsional moments in the spindles and couplings of different types of rolling mills were determined from the energy output of the driving motor and its speed. In order to determine the points at which the localisation of stresses leading to failure of the parts may occur, experiments were made on models of spindles and couplings which were fractured by the application of torsional stresses and were then annealed in order to reveal, by recrystallisation, the parts in which plastic deformation had occurred. The extensive data obtained were used to calculate the maximum stresses set up in the spindles and couplings, and their design is also discussed.

**High Speed Fatigue Testing.** R. R. Moore. (Steel, 1939, vol. 105, Nov. 27, pp. 40-41). In this general discussion of the significance of fatigue testing the author gives some brief particulars of a rotating-beam fatigue-testing machine with which 10,000 stress reversals per min. can be applied.

**The Effect of Range of Stress on the Torsional Fatigue Strength of Steel.** J. O. Smith. (Illinois University, 1939, Engineering Experiment Station, Bulletin Series No. 316). The author presents a report on an investigation of the effects of changing the range of torsional stress on the endurance limit of plain and drilled specimens of S.A.E. 3140 steel. He came to the following conclusions: (1) For ranges of torsional shearing stress other than completely reversed cycles of stress (*i.e.*, stress cycles in which the peak values are equal in magnitude but opposite in sign), steel is likely to cease to perform satisfactorily as a structural or machine member because of one of

two types of failure. First, for some stress ranges it may fail by developing large permanent deformation at the torsional static yield strength before the endurance limit is reached. Secondly, for some ranges of stress, it may fail by progressive fracture at a nominal or calculated stress below the torsional static yield strength. Endurance limits for various ranges of stress have little significance if their values exceed the static elastic strength of the steel. (2) In order to possess a high endurance limit for various ranges of torsional shearing stress, a steel which is to be used without stress concentration must also possess a high static elastic stress in addition to a high endurance limit for completely reversed cycles of stress. Heat-treated steels are, therefore, particularly desirable if they are to be subjected to ranges of stress other than completely reversed cycles of stress, for heat treatment usually raises the static strength properties more than it does the fatigue strength properties. (3) For small specimens with a stress concentration caused by a small transverse hole, the torsional-shearing endurance limit of S.A.E. 3140 steel in both the as-received and the heat-treated condition is not independent of the range of stress. The magnitude of the endurance range of stress is decreased as the maximum stress in the range increases, *i.e.*, the difference between the maximum and minimum stresses of the endurance range decreases as the maximum stress is increased.

**Contribution to the Problem of the Precipitation-Hardening of Unalloyed Mild Steels.** H. Wilhelm and J. Reschka. (Archiv für das Eisenhüttenwesen, 1939, vol. 13, Dec., pp. 273-275). The authors report on an investigation of the influence of time on the hardness and strength of specimens of mild steel containing from 0.16% to 0.28% of copper (presumably not added intentionally—*see* title), which were annealed at 650° C. and quenched in water. The specimens were tested daily at first and then at longer time intervals, some being examined after five years' storage at room temperature. In most cases the hardness values obtained within the periods of 100-1500 days after the original heat treatment showed a distinct falling off from the peak reached during the first 100 days of precipitation-hardening. The hardness, elongation, tensile strength, elastic limit and impact strength curves do not show a straight-line or any other definite relationship to time.

**The Problem of Wear in Rolling and Sliding Friction.** A. Eichinger. (Eidgenössische Materialprüfungs- und Versuchsanstalt, 1938, Oct., Report No. 121). The author discusses the physical phenomena connected with friction, dealing separately with: rolling friction between dry surfaces; rolling friction between wet or lubricated surfaces; dry or semi-liquid sliding friction; and liquid sliding friction. There are three fundamental causes of wear, which may operate simultaneously, *viz.*, (1) Mechanical influences and elastic deformation leading to fatigue of the over-stressed surface layer; (2) mutual electro-magnetic effects of the rubbing surfaces;

and (3) chemical processes in the rubbing surfaces. Wear according to (1) can be prevented by the choice of material of suitable composition and shape and by cooling and lubrication, whereas wear according to (2) can never be avoided completely. The third type of wear has been observed mainly as a consequence of dry friction, and it is due to chemical alterations of the surface under the influence of frictional heat not conducted away instantly. The author points out that it is to some extent possible to predict the wear-resistance of alloys—in particular of steels of various compositions—by studying their chemical, physical and mechanical properties.

**Magnetic Materials Testing.** J. A. Ashworth. (Bell Laboratories Record, 1939, vol. 18, Oct., pp. 49–53). The author points out that the basic characteristics of magnetic materials may be determined for the most part from the various relationships between the flux density and the magnetising force. These relationships can be represented graphically by a magnetisation curve and a series of hysteresis loops. He briefly reviews the methods and apparatus used for magnetic tests, and discusses how they have to be varied according to the properties, the shape and the dimensions of the material to be studied.

**Investigation of the Heat Treatment of 3% Chromium Magnet Steel.** N. T. Gudtsov, V. V. Polovnikov and L. S. Alekseeva. (Metallurg, 1939, No. 7, pp. 62–74). (In Russian). An investigation was carried out in connection with the substitution of the tungsten-free 3% chromium magnet steel for the more expensive 5% tungsten steel. The results obtained are already finding successful practical application. The actual composition of the steel used in the experiments was: carbon 0.85%, silicon 0.13%, manganese 0.38%, sulphur 0.008%, phosphorus 0.016%, nickel 0.16% and chromium 3.03%. The investigation included the determination of the critical points, the determination of the effect of the quenching temperature on the hardness and magnetic properties, a detailed study (by the magnetometric method) of the isothermal transformation of austenite in the steel, and, finally, a selection of the optimum heat-treatment schedule. The optimum magnetic properties were obtained by quenching from 800–850° C. The S-curves obtained showed that the times of the beginning and the end of the transformation of the supercooled austenite vary considerably, depending on the temperature of the intermediate quenching bath. The nature and structure of the austenite decomposition products depend mainly on the decomposition temperature. The optimum heat treatment to obtain the best magnetic properties and freedom from cracking is a quench from 850° C. in oil at 100° C., holding for up to 1 min. and then cooling in water.

**The Effect of Time and Elevated Temperatures on Naval Boiler Tubing.** A. P. Calvert. (Journal of the American Society of Naval Engineers, 1939, vol. 51, Nov., pp. 516–523). The author describes an investigation of the causes of failures in naval boiler tubes. Specimens



of tube 18 in. long  $\times$  1.5 in. outside dia.  $\times$  0.126 in. wall were heated in an electric-resistance furnace and subjected to pressure from a cylinder of compressed air. He came to the following conclusions : (1) The primary cause of boiler-tube failures at metal temperatures up to 1800° F. is creep and not internal or external corrosion due to heat ; (2) the oxidation of tubes is greater after 350 hr. at 1200° F. than after 1.9 hr. at 1800° F. ; and (3) proper and adequate circulation is necessary if tubes are to withstand working pressures of 600 lb. per sq. in.

**Chromium Steel Castings.** (Metallurgist, 1939, vol. 12, Dec., p. 77). This is an abridged English translation of a paper by Roesch published in Giesserei, 1939, vol. 26, July 14, pp. 357-360, in which he discusses the properties imparted to steel by the addition of different percentages of chromium. (See Journ. I. and S.I., 1939, No. II., p. 295 A.)

**Chromium-Molybdenum Steels.** (Metallurgist, 1939, vol. 12, Dec., pp. 84-86). This is an abridged English translation of a paper by Voss and Krämer in which the changes in the mechanical properties of chromium-molybdenum steels in relation to the dimensions of the specimen and the carbon, manganese and chromium contents are discussed. The paper was published in Stahl und Eisen, 1939, vol. 59, Aug. 10, p. 913. (See Journ. I. and S.I., 1939, No. II., p. 295 A.)

**The Austenitic Manganese Steels.** J. A. de Bondy. (Canadian Metals and Metallurgical Industries, 1939, vol. 2, Nov., pp. 279-281). The author discusses the development, microstructure, heat treatment and applications of steels containing 10-14% of manganese.

**The Working of S.A.E. Nickel Alloy Steels.** (Machinist, 1939, vol. 83, Dec. 2, pp. 865-876). This article consists of a number of specifications, data sheets and instructions in which the analyses, properties, methods of heat treating and machining, and the applications of the S.A.E. nickel steels are presented in a concise and convenient form.

**Nickel Alloys in the Production, Transportation, Refining and Combustion of Oil.** J. A. Rabbitt. (Japan Nickel Review, 1939, vol. 7, Oct., pp. 274-302). The author surveys the applications of the S.A.E. steels containing nickel in the plant and machinery used for boring oil wells and for the transport, refining and combustion of oil. The tensile and torsional strength, the hardness, and the heat and corrosion resistance of the alloys are also reviewed.

**Gas Industry and Nickel Alloys.** G. Tomita. (Japan Nickel Review, 1939, vol. 7, Oct., pp. 303-312). The author describes the application of nickel alloys in the plant used in the production of coal gas.

**Nickel Alloys in Mining and Utilizing Coal.** S. Niwa. (Japan Nickel Review, 1939, vol. 7, Oct., pp. 313-322). The author describes and illustrates coal-mining machinery and equipment in which the

use of nickel-steel alloys has resulted in an increased life of the components. He includes numerous analyses of the alloys for particular applications.

**Nickel Steels and the Hydrogenation of Fuels.** C. Berthelot. (Japan Nickel Review, 1939, vol. 7, Oct., pp. 323-336). After briefly explaining the principles of the hydrogenation of coal, the author discusses some of the metallurgical problems which arise owing to the high temperatures and pressures at which some units of the plant operate, pressures of 300 atm. being employed in some cases. He then describes the design of the hydrogenation converters with particular reference to the use of nickel steel.

**Corrosion and Heat Resisting Steels.** W. B. Thompson. (Canadian Metals and Metallurgical Industries, 1939, vol. 2, Oct., pp. 252-256). The author reviews the compositions of the more important corrosion- and heat-resisting steels developed in recent years and discusses in particular some new varieties of 18/8 chromium-nickel steels. The manufacture of the alloys, particularly from the casting view-point, is briefly considered.

**Tool Steels.** H. B. Chambers. (American Society for Metals, Oct. 1939: Canadian Metals and Metallurgical Industries, 1939, vol. 2, Nov., pp. 270-273). In this general discussion of the fundamental principles governing the properties and applications of tool steels, the author adopts the following four categories: (1) Those of excellent wear-resistance and poor toughness; (2) those of good wear-resistance and fair toughness; (3) those of fair wear-resistance and good toughness; and (4) those of poor wear-resistance and excellent toughness. He then divides each of these categories into three sections, which are based upon their behaviour during heat treatment. He gives the approximate analyses of some steels of the twelve types thus defined and discusses their heat treatment.

**Some Physico-Mechanical Properties of Hot-Rolled DS Steel Sheet.** V. Gridnev, L. Solov'ev and I. Kheyfets. (Metallurg, 1939, No. 4-5, pp. 44-56). (In Russian). The chemical composition of DS steel, as produced at present, is carbon 0.18-0.19%, copper 0.4-0.5%, chromium 0.4-0.6% and manganese about 0.9%. In view of the fact that the proof strength obtained in hot-rolled sheet was somewhat below the specified figure, a study was made of the effect of the cooling conditions and of the sheet thickness after rolling. The mechanical properties of the steel were improved by making use of the ageing effect produced by annealing at 400-450° C. for 20-30 min. The same result was obtained by normalising after annealing. Experiments also demonstrated that the mechanical properties could be controlled within wide limits by suitable quenching and tempering treatments. Specimens tempered for 2 hr. at 400° C. after quenching had a tensile strength of 114.5 kg. per sq. mm., a yield point of 109 kg. per sq. mm., 11.6% elongation and an impact strength of 6 kg.m. per sq. cm. Cold working caused the usual reduction in ductility and increase in strength,

the ductility being still further reduced by annealing the cold-worked metal. The impact strength is comparatively unaffected at 20–250° C., but it falls off at temperatures below 0° C. and reaches a minimum at 500° C. Abnormal changes in properties at between 250° and 350° C. are ascribed either to the precipitation of iron carbide or to the formation of a copper-rich solid solution.

**Notes on Cast Steels of High Mechanical Strength.** G. Delbart. (Bulletin de l'Association Technique de Fonderie, 1939, vol. 13, Oct., pp. 338–346). This is a French translation of a paper previously abstracted from the Transactions of the American Foundrymen's Association, 1939, vol. 47, Sept., pp. 179–194, (*see* Journ. I. S.I., 1939, No. II., p. 340 A) in which the author discusses those metallurgical factors affecting the strength of cast steels over which the foundryman can exert some measure of control.

**An Investigation into the Permissible Load Carrying Capacity of Steel Wire Ropes for Hoisting, with special reference to Deep Level Winding on the Witwatersrand Goldfields.** J. J. P. Dolan and W. G. Jackson. (Journal of the South African Institution of Engineers, 1939, vol. 38, Nov., pp. 86–124). The authors report on an investigation undertaken in the Transvaal which had the following principal objects: (1) To determine the stresses, normal and abnormal, to which a winding rope is subjected in the Witwatersrand goldfields and the condition of winding ropes throughout their operating life; and (2) to examine and analyse the autographic load-extension diagrams taken under the statutory periodic tests at the Government Mechanical Laboratory.

**An Attempt to Calculate the Mechanical Properties of Steel 12KhNZA from Its Chemical Composition.** V. Doronin. (Stal, 1939, No. 4–5, pp. 66–68). (In Russian). The chromium-nickel case-hardening steel 12KhNZA contains carbon 0.17% max., silicon 0.17–0.37%, manganese 0.25–0.55%, chromium 0.60–0.90%, nickel 2.75–3.25%, sulphur 0.03% max. and phosphorus 0.035% max. Data were obtained from specimens from 500 heats which showed the effect on the tensile properties and hardness caused by changes of 0.01% in the carbon content and of 0.1% in the silicon, manganese, chromium and nickel contents. These figures can be used to determine the mechanical properties of such steels when the analysis of the heat is known. In further investigations very fair agreement was obtained between calculated results and test data, except in the case of those relating to reduction in area in which case the former were lower than the latter.

**Foreign Standard Specifications for Grey Iron.** H. Jungbluth. (Foundry Trade Journal, 1939, vol. 61, Nov. 30, pp. 375–378). An English translation is presented of an article which appeared in Giesserei, 1939, vol. 26, Aug. 25, pp. 433–437 in which the test conditions and standard specifications for grey iron which have been formulated in various countries were compared. (*See* Journ. I. and S.I., 1939, No. II., p. 352 A).

## METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 103 A-106 A)

**Research in Relation to Steel Metallurgy.** W. H. Hatfield. (Sheffield Metallurgical Association : Iron and Coal Trades Review, 1939, vol. 139, Nov. 24, pp. 723-724). After strongly advocating the continuance and intensification of research during the war, the lecturer exhibited a colour film of some of the operations at the Brown-Firth steelworks in Sheffield, and then indicated some of the progress which has resulted from research carried out over the last twenty years; the examples he quoted showed the stage now reached in the knowledge respecting creep phenomena, plastic deformation and changes in composition due to oxidation and corrosion.

**X-Ray Analysis and the Structure of Matter.** Sir William Bragg. (Royal Society, 1939, Nov. : Nature, 1939, vol. 144, Dec. 9, pp. 961-963). The author reviews the development of the investigation of the structure of matter by means of X-rays, and shows that the recently acquired knowledge of the dimensions and arrangement of crystallites within crystals is only a preliminary success in the vast field of research awaiting further attack.

**Method of Determining the Number of Graphitisation Nodules in Malleable Cast Iron.** S. A. Saltykov. (Zavodskaya Laboratoriya, 1939, No. 4-5, pp. 428-431). (In Russian). Discussing the method suggested by H. A. Schwartz (*see* Journ. I. and S.I., 1934, No. II., p. 698) the author provides additional experimental data which, taken together with those of Schwartz lead to the formula :

$$N = 2.38 n^{1.6}$$

where  $N$  is the number of graphitisation nodules (in millions per cu. mm.) and  $n$  is the number of precipitated graphite particles per sq. mm. of the micro-section. According to the author's observations, the duration of both the first and second stages of graphitisation is directly proportional to the mean distance  $c$  between the graphitisation nodules, the values of  $c$  being given by the formula :

$$N = \frac{\sqrt{2}}{c^3}$$

**Method of Evaluating the Whitening of Cast Iron.** K. P. Bunin. (Zavodskaya Laboratoriya, 1939, No. 4-5, pp. 432-433). (In Russian). A macro-section of the casting is etched with alcoholic nitric acid until the structure of the transition layer is clearly brought out. The nature of the whitening is characterised by the curve



obtained by plotting the relative areas occupied by the "grey" and "white" constituents against the distance from the surface of the casting. The shape of this curve has been found to be a close approximation to that of the curve giving the combined and free carbon contents at different depths. The effect of any factor (*e.g.*, manganese content) on the degree of whitening may be shown by plotting the areas enclosed by the above curves against this factor.

**What Grain Size Means to the Steel User.** R. W. Simon. (Machinist, 1939, vol. 83, Nov. 25, pp. 854-856). In this paper the author discusses, from the user's point of view, the characteristics of coarse- and fine-grained steels with particular reference to their hardenability and machinability.

**Improving the Resistance of High-Speed Steel Tools.** I. Bornatskiy. (Stal, 1939, No. 6, pp. 44-46). (In Russian). The investigations were conducted on a steel containing 0.75% of carbon, 0.30% of manganese, 0.30% of silicon, 0.016% of sulphur, 0.019% of phosphorus, 4.30% of chromium, 0.08% of nickel, 17.4% of tungsten and 0.62% of vanadium, with the object of determining: (a) The effect of the maximum temperature and of the holding time on the temperature at which the martensite transformation began; (b) the influence of the temperature and holding time during the ageing of the austenite on the martensite point; and (c) the effect of the heat-treatment conditions on the life of cutting tools. The ageing of super-cooled austenite is accompanied by the precipitation of carbides along the austenite grain boundaries and a rise in the temperature of the martensite transformation on subsequent quenching. Machining tests showed the particularly beneficial results of stepped quenching (heating to 1280-1300° C., cooling in molten lead at 500° C. and holding for 3 min., transferring to a muffle furnace and holding at 650° C. for 3 hr. and final cooling in air) which increased the life of the tools to about 90% longer than that of tools quenched in the ordinary way.

**The Crystal Chemistry of Intermetallic AB<sub>2</sub> Compounds (Laves Phases).** G. E. R. Schulze. (Zeitschrift für Elektrochemie, 1939, vol. 45, Dec., pp. 849-865). Laves phases are defined as intermetallic compounds crystallising with an MgCu<sub>2</sub> or a "homœotectic" lattice. Based on energy and geometrical considerations the author comes to the conclusion that a Laves phase is composed of a metal *A* inclined to form intermetallic compounds, and a metal *B* the second electron orbit of which is incomplete. A further condition for the formation of a Laves phase is that the diameter of *B* is smaller than that of *A* by 20%. The intermetallic compounds forming Laves phases are enumerated. One of the two components (*A* as well as *B*) of several of them is iron. It is pointed out, however, that a metal in the ferromagnetic state does not tend to form Laves phases. The only ferromagnetic Laves phase known is FeBe<sub>2</sub>.

## CORROSION OF IRON AND STEEL

(Continued from pp. 107 A-108 A)

**The Fight Against the Corrosion Caused by Water.** G. Degremont. (Association des Ingénieurs sortis de l'École de Liège, Conference on the Purification of Water, June, 1939: *Revue Universelle des Mines*, 1939, vol. 15, Nov., pp. 562-568). The author discusses methods of preventing the attack of water on metals by treatment of the water, dealing with the subject under the following headings: (1) The causes of the aggressiveness of water; (2) factors affecting the protection of materials; (3) the influence of different treatments on the aggressiveness of waters; (4) different methods of neutralising water; and (5) the application of the methods described in (4) with particular reference to the treatment of acid solutions on the surface of water. He considers that more attention should be given to the treatment of water, which is often a less expensive method of preventing corrosion than the employment of special alloys.

**Corrosion by the Products of Combustion of Town Gas under Conditions of Condensation and Re-Evaporation.** F. Taylor and J. W. Wood. (Institution of Gas Engineers, 1939, Communication No. 224). The authors report on an investigation of the action of the products of combustion of town gas upon various materials which might be used in the construction of gas appliances, under conditions of condensation and re-evaporation. Several non-ferrous materials were examined, but mild steel was also included. Each material was in the form of a 1-in. tube, fitted at the top with a water-jacket and insulated along the rest of its length. The tubes were subjected to the continuous action of the products of combustion for periods of 32 days, and the experiments were conducted with town gas containing 22 g. and 5 g. of sulphur per 100 cu. ft., respectively. The test data presented include the percentage of sulphur retained in the deposit, the weight of metal in the deposit per 100 cu. ft. of gas burned, the total weight of metal lost and the total weight of the deposit formed.

**The Effect of Sulphur Dioxide on Iron and Steel.** W. Baukloh and I. Valea. (*Korrosion und Metallschutz*, 1939, vol. 15, Sept., pp. 295-298). As part of a study of the reactions between gases and solids, the authors undertook an investigation of the reactions between iron and sulphur dioxide at different temperatures, with special reference to the chemical composition and physical structure of the scale which was formed. They found that: (1) No scale was observed until a temperature of 200° C. was reached; (2) the

scale consisted of iron sulphide, ferroso-ferric oxide and ferric oxide ; (3) the greater the carbon content of the iron the less was the quantity of scale ; and (4) the rate of scale formation in moist sulphur dioxide increased linearly with time.

**Intercrystalline Corrosion of Chromium-Manganese Steels.** (Metallurgist, 1939, vol. 12, Dec., pp. 79-80). This is an abridged English translation of a paper by de Sy in which he compares the degrees of corrosion resistance of five different chromium-manganese steels when subjected to attack by electrolyte solutions. The article appeared originally in *Revue de Métallurgie, Mémoires*, 1939, vol. 36, Sept., pp. 389-399. (See p. 108 A).

**Soil-Corrosion Studies, 1937. Corrosion-Resistant Materials and Special Tests.** K. H. Logan. (Journal of Research of the National Bureau of Standards, 1939, vol. 23, Oct., pp. 515-541). The author presents the data obtained from the examination of approximately 1600 specimens of ferrous and non-ferrous materials after being buried in many different types of United States soils for periods of five to nine years. Most of the specimens were short lengths of tubing from  $1\frac{1}{2}$  to 6 in. in dia. The results showed that, in general, the addition of small amounts of chromium, copper or nickel to iron or steel had no marked effect on the resistance of the alloys to corrosion in soil, whilst ferrous alloys containing large amounts of chromium lost weight at a much slower rate than the other materials tested. The addition of nickel to chromium-iron alloys further reduced the rate of loss and the depth of the pits produced.

**What About Embrittlement ?** E. P. Partridge. (Blast Furnace and Steel Plant, 1939, vol. 27, Oct., pp. 1056-1060, 1076, 1080). The author traces the successive stages of research in the United States during the last thirty years into the causes and methods of preventing the caustic embrittlement of boiler plates.

## BOOK NOTICES

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(Continued from pp. 112 A-113 A)

DEARDEN, J. "*Iron and Steel To-day.*" 8vo, pp. 190. Illustrated. London, New York and Toronto, 1939: Oxford University Press. (Price 4s. 6d.)

This well-produced volume is one of a series entitled "The Pageant of Progress," under the general editorship of J. W. Bispham, O.B.E., M.A., B.Sc. It falls into the popular class of technical literature, and is distinguished throughout by a clear and carefully written account of the modern metallurgy of iron and steel. The author has wisely avoided that pitfall of the "armchair scientist" the assumption of a total lack of technical knowledge on the part of the reader, and one is spared the dubious subterfuges sometimes adopted to give the lay reader a hazy grasp of the basic principles underlying some complicated operation or process. Anyone interested enough to read this book will have the rudimentary technical knowledge necessary to follow the author without difficulty. Where necessary, as in the treatment of the induction furnace, the rather involved principles are explained in simple and wholly satisfactory terms. All the principal methods of production of iron and steel are dealt with in separate chapters, and there are chapters also on the working, testing and qualities of steel. The chapter headed "Tool Steel" is actually a description of the Sheffield crucible-steel process, and would have been better entitled as such, both for accuracy and in conformity with the chapter-headings elsewhere in the book. The volume is illustrated by a number of excellent photographs showing plant and operations in many of the large works in this country, and there are also many clearly drawn line diagrams to assist the reader's understanding of the text.

STEPHEN L. ROBERTON.

GREAVES, R. H., and H. WRIGHTON. "*Practical Microscopical Metallography.*" Third edition, revised and enlarged. 8vo, pp. xi + 272. Illustrated. London, 1939: Chapman and Hall, Ltd. (Price 18s.)

Some time ago a book on "The Principles of Metallographic Laboratory Practice," by G. L. Kehl, was reviewed in these pages (Journ. I. and S.I., 1939, No. I., p. 388 A), and although this new work cannot be so well known as that of Greaves and Wrighton, which first appeared in 1924, it seems worth while to refer to it here, because the two books supplement each other so conveniently from the point of view of those teaching or learning practical metallography. Since the first edition of Greaves and Wrighton appeared in 1924 it has become familiar to many generations of students and an essential feature of the book-shelves in metallographic laboratories and the homes of metallurgists. The authors do not pretend to deal with metallography in general as including the determination and interpretation of constitutional diagrams, the study of the crystal structure of metals and alloy constituents and the theory of changes in the solid state. These



subjects are considered briefly, in order to explain and systematise the results obtained by microscopic examination, but the main object of the book is to provide within a small compass a set of typical photomicrographs accompanied by a concise account of how they are obtained, what they mean and how the observed structures are related to mechanical properties. The three main features of the book are (1) the careful account of the preparation of specimens, the use of the microscope and the methods of photomicrography and macrography, (2) the descriptions of the structures obtained in alloys of industrial importance and (3) the excellent set of photomicrographs used to illustrate the methods of photomicrography and the structure of metals and alloys. Kehl's book, although also devoted to practical metallography, differs from the work under review in that it devotes much less attention to consideration of the structure of industrial alloys and deals essentially with the principles of micrography, pyrometry and thermal analysis and with such special tests as grain-size determinations.

In preparing their third edition Greaves and Wrighton have taken advantage of the opportunity provided for revision and enlargement. Various sections have been rewritten and extended. Some additions have been made to the chapters dealing with the microscope and methods of microscopic examination, and reference has been made to the latest developments of objectives and illuminants for microscopy. They might have been well advised, however, to have brought their description of the structure of hardened and tempered carbon steels more into line with modern views, for there is so much of present day knowledge about the heat treatment of carbon and alloy steels that must appear confusing to those who try to fit it into a picture created by studying a description based on earlier theories.

J. M. ROBERTSON.

MOTT, R. A., and R. V. WHEELER. "*The Quality of Coke.*" Being the Second Report of the Midland Coke Research Committee, Iron and Steel Industrial Research Council. With a Foreword by W. J. Brooke. 8vo, pp. xxv + 464. Illustrated. London, 1939 : Chapman and Hall, Ltd. (Price 36s.)

Since the cost of fuel is a major expense of pig-iron and of steel manufacture, and since, according to modern practice, the object should be that all the fuel used in an iron and steel works should pass through the coke-ovens, the quality of coke and the factors that influence it must be matters of peculiar importance to the iron and steel industry. Several Coke Research Committees are at work, but only the Midland Committee has published its collected researches in book form; this is the second such report, and it takes the story of the researches of the Committee from 1929 to 1937, with occasional excursions into 1939.

The quality of coke profoundly influences the cost of fuel in the blast-furnace. The iron-maker must have coke that will react satisfactorily in the furnace, and he will not desire to pay unnecessarily for constituents that are valueless or even detrimental for his purpose. The sections in this book that deal with the standards of commercial coke and with improving the quality of coke are overwhelmingly more important to the practical side of the industry than the remainder of the work, which records experiments designed to confirm prior views on the mechanism of coke formation. Earlier work on the elimination of breeze shows the advantages of removing breeze below  $1\frac{1}{2}$  in. or  $1\frac{1}{4}$  in., and in practice this material can be utilised in the general coke market if pains are taken to screen it into nuts and true breeze. An important section which indicates the extent of breeze formation

during handling at the furnaces should be taken to heart by all who design coke-handling plant. There follows a very detailed investigation on the sampling, analysis and testing of coke which has been necessary before any specification for furnace coke could be adopted. Some years ago coke was sold in Cumberland by carbon content; we know that something more than high carbon content is desirable for a good furnace coke, but even this modified scheme, so long as it lasted, gave excellent results. The Midland Coke Research Committee has put forward in this book a suggested specification for furnace coke, but there is as yet no suggestion that the industry as a whole is prepared to accept this specification. Presumably there must be arranged penalties for non-compliance with it. Statistics (given in fig. 55) show how greatly the quantity of coke used depends on its composition, and it might be seriously suggested that the first post-war work of the Committee should be to set its research staff the primary task of suggesting, from known data on furnace operation, a commercial basis upon which this scheme could be operated.

A very interesting development from the work of the Committee is the recognition, which has hitherto been denied in many responsible quarters, of the contention of Dr. Koppers that a reactive coke is desirable for modern blast-furnaces. In "Coke for Blast Furnaces" the authors declared that the specific reactivity of a coke "is of little direct importance in blast-furnace operation." It is now recognised in this present volume, however, that the rapid descent of the stock in modern furnaces demands a coke that will react rapidly (*see* pp. 172 and 178).

The work is not a text-book, but a record of a research extending over many years. It contains information of the greatest value to other workers, and as a work of reference it will be invaluable to all interested in coke. It will be appreciated that some of the results may be tentative only and that not everything in the book is definitive and accepted by practical men in the industry—but this fact is inherent in the nature of the book, and the authors would be the last to claim that experimental results were always directly applicable to practice. Nevertheless, the Midland Coke Research Committee is to be congratulated on a fine piece of work.

G. E. FOXWELL.

TAYLOR, E. R. "*Definitions and Formulæ for Students (Metallurgy)*." Sm. 8vo, pp. iv + 50. London, 1939: Sir Isaac Pitman and Sons, Ltd. (Price 6d.)

In this little booklet the items are grouped under six headings designed to make reference easier, but the modest dimensions of the work might have included all the sections without subdivision and with the omission of one or two examples of cross-reference that occupy valuable space. One cannot expect an inexpensive booklet of this type to be in any way exhaustive, but the author has succeeded in dealing with a surprisingly large number of items. The space devoted to the various sections is roughly in accordance with the complexity and general importance of the subjects covered, and, in view of the wide scope of the whole subject, it would be rash to suggest any different apportionment of space. Where criticism may legitimately be levelled is at the misleading and partial definitions given under certain of the entries. Thus, "Mechanical Twins" may reasonably be taken to be a term applicable only to Neumann Bands in iron, and the definition of "Globalizing" suggests, firstly, that cold work is essential, and secondly, that it is the cold work that brings about the structural change. In this last item, too, the term defined is used in giving the

explanation. With a little more attention to the wording of the definitions such slips would be rectified and the value of the book to students of metallurgy enhanced.

STEPHEN L. ROBERTSON.

WILLIAMS, R. S., and V. O. HOMERBERG. "*Principles of Metallography*." Fourth Edition. 8vo, pp. ix + 339. Illustrated. London, 1939: McGraw Hill Publishing Co., Ltd. (Price 23s.)

The previous editions of this book appeared in 1919, 1928 and 1935 respectively, but it is probably true to say that it is not so well known in this country as a number of other books which have a shorter history behind them or have passed through fewer editions. None of these books is exactly the same as this one, and no two technical books are ever quite alike, but frequently, in spite of differences in the subjects treated or the method of treatment, several different books appear to be equally suitable for a particular purpose. This book was written to meet the needs of those students of general science or engineering who do not specialise in metallography, but who will use it to a limited extent in connection with their professional work. A number of other books have been written with a somewhat similar object, and although they all differ in size and with respect to the subjects selected for emphasis, they all appear to be more or less equally effective for the purpose of introducing people to the subject. In the present work attention is confined to six subjects—namely, constitutional diagrams, plastic deformation, industrial non-ferrous metals, iron and steel, macroscopic examination of steel and metallographic laboratory methods. In view of the limited amount of space available for describing the fundamental features of constitutional diagrams before going on to deal with the complications of the copper-zinc, copper-tin and iron-carbon diagrams, it is doubtful whether the authors were well advised to endeavour to consider constitutional diagrams in terms of the phase rule, for, while this is of great utility in determining diagrams, it does not have much bearing on their use in studying the nature and properties of non-ferrous alloys and the heat treatment of steel. The chapter on plastic deformation and annealing was written by M. Cohen, and gives a very good account of this subject. In the chapter on non-ferrous alloys attention is given to aluminium alloys, copper alloys, bearing metals and age-hardening, while in the chapter on iron and steel, the full iron-carbon diagram, heat treatment, hot-working, cold-working, grain-size control and the effects of impurities and alloying elements are described. The chapter on the macroscopic examination of steel deals with the solidification of ingots and the resulting macrostructure, and with the macrostructure of forgings. The last chapter contains brief accounts of thermal analysis, the preparation of metallographic specimens, the metallurgical microscope and photomicrography.

J. M. ROBERTSON.

## REFRACTORY MATERIALS

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(Continued from pp. 118 A-123 A)

**Refractory Material.** E. Belani. (Teknisk Tidskrift, 1940, vol. 70, Jan. 13, Bergvetenskap, pp. 7-8). (In Swedish). A brief review is presented of methods of making crucibles for melting pure metals and alloys. For melting pure iron the use of either Greek magnesite prepared by the acetate method or electrically sintered magnesite is not recommended, but a mixture of Greek magnesite with 15% of cleaned and burnt zirconium silicate makes an excellent crucible. With such crucibles, however, the danger of the iron taking up silicon and phosphorus must be guarded against; this is done by mixing the finely ground magnesia, burnt at 1600° C., with 10% by weight of magnesium chloride ( $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ ), or with shellac dissolved in alcohol. The mixture is then rammed in a mould; on completion of the ramming one-half of the mould is removed and the crucible allowed to dry in the other half; it is then fired at about 1600° C. Such crucibles can be used for melting iron and nickel, and a very high degree of purity is maintained.

**Deformation of Insulating Firebrick under Load.** C. L. Norton, jun., and V. J. Duplin. (Journal of the American Ceramic Society, 1940, vol. 23, Jan., pp. 22-25). The authors describe a method of applying loads to insulating firebricks heated throughout to thermal equilibrium in a specially designed electrically heated furnace. Sixteen commercial brands of insulating firebrick were tested between 1900° and 2300° F. under several different loads. No correlation was found to exist between the density of the brick and its strength at these temperatures, or between the strengths at normal and at elevated temperatures.



## FUEL

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(Continued from pp. 124 A-125 A)

**Specific Gravity Coal Washing with Special Reference to the Tromp Process.** C. W. H. Holmes. (North of England Institute of Mining and Mechanical Engineers : Colliery Guardian, 1939, vol. 159, Dec. 15, pp. 861-864; Dec. 21, pp. 899-902). After stating that the use of true liquids or solutions of high density for the specific-gravity washing of coal is extremely limited, the author discusses the theory of those methods in which a suspension of heavy, finely divided material in water is employed. These he classifies as stable and unstable suspensions. He surveys these groups in turn, discussing the methods of control employed and their relative advantages and limitations. The Tromp process is the only one that purposely employs an unstable suspension, the solid medium consisting of either magnetite or burnt pyrites. The author describes the Tromp process in detail and then points out four ways in which this modern washing process is more efficient than, for example, the use of jigs; these are: (1) A higher yield of washed coal for an equivalent ash content is obtained; (2) the ash content of the washed products is more uniform; (3) there is an increased yield of screened sizes due to decreased breakage during washing; and (4) the absence of degradation is reflected in the appearance of the washed coal, which is not only free from unsightly pieces of middling and flat shale, but the nuts retain their corners and look much more attractive than the normal Baum-washed coal. An abridged version of this paper appeared in *Iron and Coal Trades Review*, 1939, vol. 139, Dec. 22, pp. 859-860, 863.

**Notes on Froth Flotation.** C. W. H. Holmes. (*Colliery Engineering*, 1939, vol. 16, Oct., pp. 364-365, 368; Nov., pp. 392-394; 1940, vol. 17, Jan., pp. 17-19). After stating several reasons why the froth-flotation process of cleaning very fine coal is used more extensively on the Continent than in Great Britain, the author discusses the seven principles, laid down by Berthelot, which must be followed to ensure the success of this process. These are: (1) Careful sizing before flotation; (2) control of the pulp density; (3) maintenance of a homogeneous feed; (4) retreatment of the separated products; (5) isolation of the flotation water circuit; (6) disposal of the shale; and (7) dewatering of the clean-coal froth. Having stated these general principles in Part I., the author proceeds in the subsequent parts to show how they are applied in industrial operation, giving more detailed information regarding the general layout of a complete plant, the power required and the cost involved in the various operations.

**Extending the Applications of Pulverised Coal.** (Iron and Coal Trades Review, 1939, vol. 139, Dec. 22, p. 863). Some recent developments in the design and operation of coal-pulverising equipment for small boiler installations are described.

**Electrical Equipment of Coke-Oven Plant.** (Engineer, 1939, vol. 158, Dec. 29, pp. 644-645). A description is given of the electrically driven equipment of the coke-ovens at the Corby Works of Stewarts and Lloyds Ltd. (See p. 4 A).

**Carbonizing Properties and Petrographic Composition of Sewell Bed Coal from Wyoming Mine, Wyoming County, W. Va., and the Effect of Blending this Coal with Alma Bed Coal.** A. C. Fieldner, J. D. Davis, W. A. Selvig, R. E. Brewer, C. R. Holmes, D. A. Reynolds and G. C. Sprunk. (United States Bureau of Mines, 1939, Technical Paper No. 601).

**Crystallite Growth during Carbonisation.** H. E. Blayden, H. L. Riley and A. Taylor. (Northern Coke Research Committee, Newcastle-on-Tyne: Journal of the American Chemical Society, 1940, vol. 62, Jan., pp. 180-186). The authors describe a detailed X-ray and chemical study of the changes which occur in the solid phase during the carbonisation of two South Wales anthracites, an American anthracite, lignin and an Irish peat, and discuss the results obtained. The investigation was concerned particularly with the crystallite growth during carbonisation in the temperature range 400-2200° C.

**The Assessment of Coals Liable to Damage Oven Walls.** R. A. Mott and C. E. Spooner. (Fuel in Science and Practice, 1939, vol. 18, Nov., pp. 329-344; Dec., pp. 371-379). The authors report on their investigations made with the object of establishing a standardised form of laboratory test which would enable the distinction between dangerous and non-dangerous coking coals to be drawn more precisely, and, for dangerous coals, would enable their degree of danger to be specified. In reviewing the recognised methods of testing, the authors disagree with one of the conclusions in the United States Bureau of Mines Report of Investigations No. 3451, *i.e.*, that cokes from all coals shrink to about the same extent (*see* Journ. I. and S. I., 1939, No. II., p. 255 A). They describe the Koppers large- and small-scale swelling tests, the Sheffield University Laboratory test and the Nedelmann, Baum-Heuser and United States Bureau of Mines tests. Their conclusions are as follows: (1) It is possible to assess most coals which are liable to damage oven walls in a small-scale laboratory test as satisfactorily as in the larger-scale tests. (2) Coals which swell abnormally (over 200%) in the Sheffield University Laboratory coking test may require to be tested on a larger scale owing to the rather fast rates of heating in the small-scale test. (3) It is essential, in all tests, when assessing dangerous coals, to standardise the apparatus and procedure exactly. (4) The first essential is to ensure that a temperature of at least 900° C. is obtained in the coal, and for this purpose, using

gas-heating in small-scale tests, eight waste-gas off-takes are desirable. (5) The behaviour of dangerous coals may be assessed either by measurement of the swelling pressure (Baum-Heuser or Nedelmann tests) or by the actual swelling as a percentage. This should be supplemented by measurement of the percentage contraction. Since the Koppers test enables the percentage contraction to be determined under a standard load, it is, therefore, when modified as stated above, the most serviceable. (6) In assessing, by laboratory tests, the liability of coals to damage oven walls, the measurement of the contraction is of more significance than the measurement of the swelling.

**Advantages of Coal Carbonization as Exemplified in the Curran-Knowles Process.** M. D. Curran. (Mining and Metallurgy, 1939, vol. 20, Nov., pp. 500-502). The author gives some particulars of a process of coal carbonisation which is finding favour in Illinois. Low ovens are used in this process which are 8-10 ft. wide and up to 40 ft. long. Small coal up to  $\frac{5}{16}$  in. is charged to form a bed about 12 in. thick. Fire-clay bricks are used throughout in the construction of the ovens except for the floor and flues under the floor, which are made of silica bricks. The gases leave the oven at a temperature about 1000° F. below that experienced with the usual vertical type of oven. This Curran-Knowles oven can be heated up and cooled off without serious damage, and there is also no danger to the oven structure when highly-expanding coking coals are used. Experience gained since 1934 shows that about 45% of the gas produced from the coal is required to heat the ovens and to supply power to the plant.

**Physical and Chemical Properties of Cokes Made or Used in Washington.** H. F. Yancey, R. E. Zane, R. W. Fatzinger and J. A. Key. (United States Bureau of Mines, 1939, Technical Paper No. 597). The authors examined twenty-one samples of coke, fourteen of which had been produced in Washington, whilst one of the samples was of English origin (from the Tyne district). The physical appearance of the samples was compared and they were subjected to standard shatter, agglutinating and tumbler tests. In addition, the authors determined for each sample the chemical composition, the specific gravity, the ignition temperature, the reactivity in carbon dioxide, the combustion rate and the influence of the carbonising temperature on the combustibility. A new method was developed for the estimation of the combustibility. This consisted of burning in an electric furnace a 1-g. sample of coarse-grained coke in a wire basket suspended from a spring and measuring the contraction of the spring caused by the decreasing weight of the sample as it burned.

**Fuel Efficiency and Costs in the Iron and Steel Industry.** D. D. Howat. (Iron and Steel, 1939, vol. 13, Dec., pp. 72-74; 1940, Jan., pp. 114-116). The author quotes figures relating to the carbonisation of coal and the consumption of town gas, coke-oven

gas and blast-furnace gas in Great Britain, from which he demonstrates that a large volume of the coke-oven gas produced is burned in an inefficient manner. He then discusses the costs and efficiency of long-distance gas-grid systems in Germany and Belgium. Finally he presents a fuel flow-sheet of an unbalanced coke-oven and iron and steel works which could supply surplus coke-oven gas and electricity to a national grid system, and discusses the revenue and expenditure relating to the fuel supply and disposal at a plant producing 10,000 tons of pig-iron per week.

**The Combustion Turbine, Its History, Present Position and Future Prospects.** A. Meyer. (Stahl und Eisen, 1939, vol. 59, Dec. 28, pp. 1373-1379). The author surveys the development of the combustion turbine from the time of Barber's first patent in 1791. In this survey he includes a schematic diagram of a Holzwarth turbine with two gas chambers which has been in operation since 1933 using blast-furnace gas. The satisfactory results achieved with it have led to a 5000-h.p. turbine of the same type being ordered. The author suggests that a combustion turbine could be used at an ironworks in conjunction with the blast supply and the system of stoves.

**Gas Washing.** A. J. Boynton. (Steel, 1939, vol. 105, Dec. 4, pp. 50-53). The author describes the principles of a new type of blast-furnace-gas washer which has been developed in the United States. The principal feature of this washer is the incorporation of a number of high-pressure nozzles which spray water at 150 lb. per sq. in. through a venturi under which is a deflector cap with two toothed rims which cause intimate contact between the dust and the water. The design is such that the distance between the venturi and the deflector cap can be adjusted from outside the tower. The nozzles can also be adjusted and cleaned from outside the tower. After cleaning, the solid material remaining in the gas amounts to 0.015 grain per cu. ft., and of this material 82% is below 2 microns in size. When operated with a blast-furnace producing 1000 tons of iron per day, the power requirements are: 156 h.p. for the high-pressure water, 57 h.p. for the low-pressure water and an additional load of 190 h.p. on the blowing engines due to the back pressure; this works out at 4.5 h.p. per 1000 cu. ft. of gas per min.

**Improvements in the Technique of Long-Distance Gas Supply.** W. Wunsch. (Zeitschrift des Vereines deutscher Ingenieure, 1940, vol. 84, Jan. 6, pp. 2-10). The author describes the developments in recent years of the long-distance gas grid of the Ruhrgas A.-G. These relate mainly to the introduction of high-pressure gas systems and the alterations necessitated by the technique of gas purification. The design of pipes, condensers and gasometers is discussed and the prevention of soil corrosion of the pipes is briefly considered.



## PRODUCTION OF IRON

(Continued from pp. 126 A-128 A)

**The Manufacture of Pig Iron in America.** W. A. Haven. (Iron and Steel Institute, 1940, *see* this Journal, Section I.). In this paper on the manufacture of pig iron in America, the author's specific purpose is to describe the designs, equipment and practices which characterise practically all modern American blast-furnaces, notwithstanding some great differences in the nature of the raw materials used in the principal producing districts.

The chief pig-iron-making districts are first reviewed briefly (Mexico, Nova Scotia, Southern or Alabama District, Rocky Mountain District, Eastern New York and Pennsylvania District, Mid-Western District), and then data on the iron ores of the Lake Superior District are presented (chemical qualities, iron content, beneficiation, reducibility, physical characteristics, output). Next, a description of the transportation of Lake ores (distances and charges, storage facilities, Lake carriers) is followed by an account of Appalachian coking coals and coke (river transportation, transport costs, mining methods, quality of coal, coke-ovens and blast-furnace plant, coke quality). Attention is then directed to blast-furnace plant and equipment, and detailed consideration is given to raw-materials unloading facilities, raw-materials storage, stock-house bins, bottom and top charging equipment, the stack, the cooling, the lining and dimensions of blast-furnaces, casting facilities, metal and slag handling, power plants and blowers, hot-blast stoves, gas-cleaning equipment, and sintering and sintering plant. Finally there is a short section on blast-furnace practice in America. Numerous illustrations and tables of data are included.

**Pig-Iron Works in Norrbotten from the Manufacturing Point of View.** (Teknisk Tidskrift, 1939, vol. 51, Dec. 23, pp. 565-569). (In Swedish). The economic aspects of erecting two blast-furnaces near Luleå in Norrbotten (the northernmost province of Sweden) for the production of pig-iron from Swedish raw materials (*see* p. 126 A) are compared with those arising from an alternative proposal to erect plant for the production of sponge iron.

**Charging Bells for Wide-Mouthed Blast-Furnaces.** V. Sorokin. (Stal, 1939, No. 7, pp. 1-5). (In Russian). Four new types of distributor for blast-furnace bells are suggested and discussed. All are intended for use in furnaces up to 8 m. in diameter. The action of a charging bell tested on the No. 3 blast-furnace of the Nadezhdenskiy works (3.6 m. diameter) is then dealt with. This new type of bell resulted in an appreciable saving of charcoal.

**The Pig-Iron Casting Machine Used at the Duisburg Kupferhütte.** (Génie Civil, 1940, vol. 116, Jan. 20, pp. 53-54). An abridged French translation of a paper by Koch describing a German casting machine for pig iron is presented. The article appeared originally in Stahl und Eisen, 1939, vol. 59, June 29, pp. 749-753 (*see* Journ. I. and S.I., 1939, No. II., p. 188 A).

**Flexibility.** R. Trautschold. (Steel, 1940, vol. 106, Jan. 8, pp. 45-46). The author describes briefly a metering and recording system installed at an American ironworks where four blowing engines serve four blast-furnaces in any combination. The system is designed to show the volume of blast supplied to any furnace at two control positions simultaneously, namely, at the blowing-engine house and on the furnace floor.

**Development of Blast-Furnace Tuyères.** J. B. Fortune. (Iron and Steel, 1939, vol. 13, Dec., pp. 66-70). The author reviews the history of the improvements in blast-furnace tuyere design, giving numerous diagrams of the various stages of development. He compares the properties of cast and forged copper tuyeres.

**The Reduction of Titanic Acid with Solid Carbon and with Carbon-Bearing Iron.** W. Baukloh and R. Durrer. (Stahl und Eisen, 1940, vol. 60, Jan. 4, pp. 12-13). The authors studied the possibilities of the reduction of titanium oxide so as to prepare data relative to the reduction of titanium-bearing iron ores. They report on an investigation of the behaviour at high temperatures and *in vacuo* of mixtures of titanic acid and graphite, and of titanic acid, graphite and iron. The results demonstrated the accelerating influence of the presence of iron on the reduction of the titanic acid, which they ascribe to the dissolution in the iron of the titanium carbide formed. They also determined the amounts of titanium taken up from a titanium-bearing slag by molten irons containing 4.1% and 2.7% of carbon at various temperatures in the range 1250-1700° C. The amounts taken up were almost the same in both cases and increased from about 0.1% at 1250° C. to about 1.9% at 1700° C.

**Reduction of Iron Ores under Pressure by Carbon Monoxide.** M. Tenenbaum and T. L. Joseph. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1134: Metals Technology, 1939, vol. 6, Dec.). The authors report on the results of their experiments, in which they compare the rates and degrees of reduction achieved when reducing cubes of limonite iron ore with hydrogen and with carbon monoxide under pressure. The results obtained with hydrogen have been previously described (*see* Journ. I. and S.I., 1939, No. I., p. 207 A). The comparison showed that: (a) The reduction is more rapid with hydrogen, and the rate of reduction was increased by 40% by doubling the pressure; (b) pure carbon monoxide reduced the samples at a rate equal to about one-fourth of that of hydrogen, and doubling the pressure of the former increased the rate by about 23%; (c) when the carbon monoxide was diluted with sufficient nitrogen to form a

mixture equivalent to the gas in a blast-furnace bosh, the rate of reduction was reduced by 50%, but doubling the pressure increased this rate by 20%; and (d) the substitution of 8.2% of carbon dioxide for an equal portion of carbon monoxide in the bosh gas reduced the rate of reduction still further, whilst increasing the pressure in this case accelerated the reduction initially but tended to retard the process in its later stages.

**A Method of Controlling the Blast-Furnace Process from the Amount of Flue Dust.** V. Koloskov and P. Korostik. (Stal, 1939, No. 7, pp. 6-10). (In Russian.) An apparatus is described in which blast-furnace gas is freed from dust in a dry dust separator. The dust collected can be weighed at regular intervals. Observations showed that there existed a definite connection between the amount of dust carried by the gases and certain figures characterising the blast-furnace process, in particular the silicon content of the pig-iron and the consumption of coke. A nomogram has been constructed from which the amounts of ore which will be reduced with a given coke consumption can be calculated from the figures obtained from the dust-measuring instrument.

**The Production of Electrolytic Iron.** F. Halla. (Korrosion und Metallschutz, 1939, vol. 15, Nov.-Dec., pp. 380-387). The author reviews the technical processes for the production of electrolytic iron, making particular reference to the process carried out at the Cwmfelin Works of Richard Thomas and Co., Ltd. Neither this process nor any of the others have, however, proved economic for mass production. He gives a brief account of his own experiments carried out with an insoluble anode and a flowing electrolyte, but he does not consider this method to be suitable for technical application.

**Heavy Industries of the German Reich.** (Iron and Coal Trades Review, 1939, vol. 139, Nov. 24, pp. 720-721; Dec. 1, pp. 763-764). (Conclusion of a series of articles, see p. 74 A). It is shown that the production of coal in Germany has been driven to a maximum for some time past by mechanisation, by recalling pensioned miners to the pits, and by working longer hours. Finally, the position of the German coal export trade with special reference to the conditions created by the blockade is reviewed.

**Some Economic Measures for the Increased Efficiency of an Iron and Steel Works.** W. Schubert. (Archiv für das Eisenhüttenwesen, 1939, vol. 13, Dec., pp. 277-281). The author gives twelve examples of economic measures which have been put in operation at a German iron and steel works and have led to increased production and efficiency. These measures are concerned with the adaptation of existing wage agreements to changes in processes, reducing idle time in a rolling mill, reducing the number of analyses and the amount of overtime in a laboratory, improved equipment and standardisation, &c.

## FOUNDRY PRACTICE

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(Continued from pp. 129 A-132 A)

**Ten Years' Progress in Cast Iron.** J. G. Pearce. (Metallurgia, 1939, vol. 21, Dec., pp. 41-42, 46). The author reviews the development of the iron-founding industry during the last decade, referring mainly to the conditions in Great Britain. He deals with the subject under the following headings: Foundry practice; melting practice; alloy additions and heat treatment; malleable cast iron; high-duty irons; heat, corrosion and wear resistance; graphite refinement; centrifugal casting; vitreous enamelling; and foundry education.

**Types of High-Duty Cast Irons.** A. J. N. Smith. (Foundry Trade Journal, 1940, vol. 62, Jan. 11, pp. 51-53). The author divides high-duty cast irons into two groups, *viz.*, those with high strength properties and those which have some other high-duty characteristic such as corrosion resistance. Those in the latter group are referred to as "special irons." The development of high-strength inoculated cast irons from those produced by the Lanz "Perlit" and Emmel processes is described, and particular consideration is given to alloy cast irons. Among the special qualities considered are various austenitic nickel-irons and martensitic chromium-nickel irons, as well as those with high silicon, chromium and aluminium contents.

**Producing Malleable Castings in a Modern Foundry.** (Foundry, 1939, vol. 67, Dec., pp. 22-27). A profusely illustrated account is presented of the foundry plant and operations at the malleable cast-iron department of the General Motors Corporation, Saginaw.

**Methods of Testing Bonding Clay.** N. J. Dunbeck. (Foundry, 1939, vol. 67, Dec., pp. 30, 104, 106, 109). The author describes some precautions which should be taken to ensure accurate results in the testing of bonding clays for foundry use.

**Production of Oil Engine Castings.** R. C. Shepherd. (Journal of the Institution of Production Engineers, 1939, vol. 18, Nov., pp. 445-460). After enumerating the difficulties which production engineers have had to contend with in order to obtain a better and more uniform quality of castings, to remedy such defects as dimensional inaccuracies, blowholes, excessive shrinkage, and to avoid excessive weight, the author describes and discusses the procedure and plant used in the manufacture of oil-engine castings at a modern foundry.

**Alloy Iron Cylinder Blocks for Truck Engines.** (Metal Progress, 1939, vol. 36, Dec., pp. 735-743). An illustrated account is given of the operations carried out at the Mack Manufacturing Corpora-



tion, New Brunswick and Plainfield, New Jersey, for the production of alloy iron cylinder blocks for motor lorry engines.

**Castings for Enamelling.** J. A. Donaldson. (Institute of British Foundrymen: Foundry Trade Journal, 1939, vol. 61, Dec. 14, pp. 405-406). After briefly describing the process of enamelling iron castings, the author discusses some points which the casting designer should observe with a view to ensuring a good finish when the casting is enamelled. He also points out how the composition of the metal and the foundry practice affect the adherence and quality of the enamel coating.

**The Latest Foundry of The Midland Electric Manufacturing Co., Ltd.** V. C. Faulkner. (Foundry Trade Journal, 1940, vol. 62, Jan. 11, pp. 41-45). The author gives an illustrated description of the foundry of The Midland Electric Manufacturing Co., Ltd., which includes a mechanised continuous casting plant, fettling shop and pattern shop.

**Steel Foundry.** H. W. Maack. (Steel, 1940, vol. 106, Jan. 8, pp. 38-41). The author describes some of the improvements in the equipment of a Chicago steel foundry. The equipment includes: (a) Three electric-arc furnaces of 2, 5 and 7 tons capacity with swinging roofs and charging hoppers with which they can be charged in 3 min.; (b) water-cooled slag skimmers; and (c) three gas-fired heat-treatment furnaces with recording pyrometers and automatic temperature regulators.

**Some Notes on Liquid Shrinkage and Contraction.** E. Longden. (Institute of British Foundrymen: Foundry Trade Journal, 1940, vol. 62, Jan. 25, pp. 81-84). The author considers the foundryman's problems arising from the shrinkage of metal on solidification and the contraction of castings on cooling. He mentions two methods of reducing the amount of riser metal necessary to feed a casting. One is the use of compounds which produce exothermic reactions, thus prolonging the fluidity of the riser or header; this has only achieved limited success. The other method is to apply heat to the header by an electric arc struck between the electrode and the metal; this has met with reasonable success. The author also advocates the provision of ample head pressure in conjunction with generous gas outlets in the moulds and cores in order to reduce the porosity of castings.

**Castability of Alloy Steel Castings.** R. J. Wilcox. (Foundry, 1939, vol. 67, Dec., pp. 28-29, 94, 96). The author discusses the castability and mechanical properties of silicon, chromium-molybdenum and chromium-nickel steels.

## PRODUCTION OF STEEL

(Continued from pp. 133 A-137 A)

**New Investigations and Knowledge Concerning the Course of the Basic-Bessemer Process.** W. Eichholz, G. Behrendt and T. Kootz. (Stahl und Eisen, 1940, vol. 60, Jan. 25, pp. 61-72). The authors refer to the difficulties encountered when endeavouring to obtain samples of metal from a Bessemer converter during the first stages of the blow and to the consequent lack of data from which to study this part of the process. They describe and illustrate a special form of sampling spoon with which samples could be withdrawn from the converter at all stages of the blow, and killed in the spoon with a little aluminium in a container fastened to the inside of the spoon at the bottom. By this means samples from over a hundred melts were taken and analysed and the authors discuss the results obtained, presenting many graphs showing the changes in the silicon, manganese, phosphorus, sulphur, vanadium, nitrogen and oxygen contents in relation to the blowing time. The processes investigated included the blowing of several melts of stahleisen containing manganese in the range 2.0-3.5%. This iron contains more silicon, manganese and carbon than basic iron, and the heat produced in the reduction of these elements creates a large reserve of heat, with the result that there is a greater temperature range available for the control of the refining process with open-hearth iron than there is with basic iron. In general, the data obtained showed that the refining of iron in the Bessemer converter is largely independent of the manganese and phosphorus contents of the iron and that, contrary to the generally held opinion, there is ample heat available in the blowing of open-hearth iron for the process to be successful in practice.

**Practical Aspects of Steel Making.** C. L. Altenburger. (Iron and Steel Engineer, 1939, vol. 16, Dec., pp. 17-21). The author discusses the influence of the physical properties and, more particularly, the chemical composition of pig iron and scrap used in steel making. He also considers the effect on the finished steel of varying the proportions in which these two materials are charged.

**The Melting of Heat-Resisting Steel for Casting in a Basic Open-Hearth Furnace.** M. Kolosov and N. Keys. (Stal, 1939, No. 7, pp. 19-20). (In Russian). Brief details are given regarding the process used for melting 4-6 ton heats of heat-resisting steel (carbon 0.13-0.14%, silicon 1.74-3.02%, manganese 0.78-1.10%, phosphorus 0.028-0.062%, sulphur 0.016-0.024%, chromium 2.91-4.13%, molybdenum 0.40-0.42%, aluminium 0.2-0.4%) in a 7-ton oil-fired open-hearth furnace. The temperature of the tapped metal was

1510–1530° C. and it was poured from a fireclay-lined ladle (diameter of opening 45 mm.) with a magnesite stopper. The steels from the various heats were cast into 100-kg. billets which were used in a sheet-normalising furnace at temperatures of 850–1050° C. in contact with the products of combustion. The behaviour in service of billets made of steels with compositions between the above limits is referred to.

**Experience with Stakhanovite Heats in Magnitogorsk Open-Hearth Furnaces.** N. Selivanov and A. Dement'ev. (Stal, 1939, No. 7, pp. 11–14). (In Russian). The characteristic features of Stakhanovite methods applied to forty heats in open-hearth furnaces are considered. Using these methods, a heat in the 185-ton furnace (scrap-ore process with 75–85% molten pig-iron) takes from 6 to 7 hr. Fettling of the furnace is done partly during the finishing of the heat as well as during, and immediately after, tapping. The gas is not turned off and the time of tapping and charging is reduced to a minimum. Consideration of the various stages of melting, &c., leads to the conclusion that it should be possible to reduce the duration of a heat to 5 hr. 10 min. with the existing thermal capacity. The heat supply to the furnace is considered and some data are given characterising the properties of steels produced by these rapid methods.

**Desulphurization of Pig Iron with Calcium Carbide.** C. E. Wood, E. P. Barrett and W. F. Holbrook. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1131: Metals Technology, 1939, vol. 6, Dec.: Foundry Trade Journal, 1940, vol. 62, Jan. 25, pp. 73–76). The authors discuss the theory and practice of desulphurising pig-iron and steel with calcium carbide. They describe in detail suitable mechanism for adding the calcium carbide to the ladle or bath, and present comprehensive tables showing the degree of desulphurisation achieved under various conditions. As to the commercial value of the process, the authors state this will depend on the ultimate cost of the treatment of large amounts of metal and on the demand for metal containing less than 0.02% of sulphur. The process appears to offer some advantages over the use of alkalies for producing metal with an extremely low sulphur content. As a sulphur content of 0.02% is approached the efficiency of alkalis decreases rapidly, whilst at that figure carbide continues to be effective. Metal containing even as little as 0.01% of sulphur can be produced at a cost that is not excessive. It was found that the best results were obtained by placing a mixture of calcium carbide and common salt in the bottom of the ladle immediately before tapping. In blast-furnace practice part of the cost of the carbide treatment can be met by operating the furnace on a more acid slag, thus lowering the coke consumption, increasing the production of iron and obtaining smoother working.

**Slag Control.** J. B. Malloy. (Steel, 1939, vol. 105, Dec. 25, pp. 48–51. The author describes the application of slag control in

open-hearth practice as an economical means of producing the desired quality of low-carbon rimming steel for rolling into strip. He describes the appearance and gives the ferrous oxide content and lime/silica ratio of sixteen different open-hearth slags and reproduces some graphs which relate these data to the oxygen and manganese contents of the steel and to the amount of aluminium required for deoxidation.

**The Removal of Liquid Slag from Slag Pockets.** A. Mamot. (Stal, 1939, No. 4-5, p. 24). (In Russian). This short illustrated note contains the suggestion of collecting the liquid slag which drains from the slag pocket in a pot lined with old bricks with an intermediate layer of sand. The pot is placed on a trolley and, when full, it is run out and tipped, the pot being used again after being provided with a new lining.

**Electrically Manufactured Steels.** H. A. Sieveking. (Institution of Electrical Engineers, Nov. 20, 1939: Preprint). After a brief description of the electric-arc and H. F. induction furnaces, the author reviews the main features of the products obtained and discusses the advantages and disadvantages of these two types for meeting specific requirements of steel melting. Electricity consumptions are next dealt with and operating results for twenty arc and twenty-five induction furnaces are given. The effect of the form of tariff and methods of operation on the cost of electric steel is also discussed, and some indication is given of the means whereby the costs may be kept in check. In order to determine the present position of electric steel production the author has compared the relative output of all classes of steel for the eleven major steel-producing countries. A particularly detailed analysis, covering a period of twenty-one years, is made for Great Britain, the United States, and Germany, *i.e.*, the three countries having the largest output of steel. In conclusion, the author emphasises that the present production of electric steel forms only a small proportion of the total output in Great Britain. He points out, however, that this proportion could be increased by an increased use of the hot-charge process.

**The Degrees of Oxidation in Coreless Induction Furnaces.** H. Weitzer. (Stahl und Eisen, 1939, vol. 59, Dec. 21, pp. 1353-1356). With a view to making the best possible use of alloying elements in the German metallurgical industries whether in the manufacture of alloys or in the remelting of alloy scrap, studies have been made of the results obtained with different kinds of furnaces. In this paper the author considers the losses due to oxidation of the elements carbon, manganese, chromium, nickel, cobalt, tungsten, molybdenum, tantalum, niobium, zirconium and titanium in the manufacture of alloy steels in acid coreless induction furnaces. He also compares these losses with those experienced with basic arc furnaces.

**The Rational Construction of the Stopper Mechanism in Steel Teeming Ladles.** A. Novik. (Stal, 1939, No. 7, pp. 15-18). (In



Russian). The various types of failures associated with the stopper mechanism are analysed and their causes, some of which relate to the design of this mechanism, are discussed. A stopper mechanism designed by the author is described. The chief feature of this mechanism is that it permits a change in position of the slider in a vertical plane.

**"Tailor-Made" Steels.** T. Grey-Davies. (Sheet Metal Industries, 1939, vol. 13, Dec., pp. 1429-1430; 1940, vol. 14, Jan., pp. 27-28, 35). Continuation of a series of articles (*see* p. 81 A). In Part XIV. of this series the author pays particular attention to the design and materials of which ladle stoppers are made and points out the defects which can arise in an ingot which may only be detected in a finished sheet due to a running or dribbling stopper. He also presents Hruska's table showing the variations in the rate of flow of steel from a ladle through nozzles  $1\frac{1}{4}$ ,  $1\frac{1}{2}$  and  $1\frac{3}{4}$  in. in dia. as the height of the metal in the ladle decreases. The author devotes Part XV. to descriptions of the basic and acid Bessemer processes of steelmaking.

**Rimming Steels.** R. H. Myers. (Swansea Technical College Metallurgical Society, Jan., 1939; Iron and Steel, 1939, vol. 13, Dec., pp. 75-78). The author considers observations made during the freezing of rimming steel ingots and explains the factors which tend to promote or reduce the evolution of gas. (*See* Journ. I. and S.I., 1939, No. II., p. 328 A).

**Columnar Structure in Steel Ingots.** (Metallurgist, 1939, vol. 12, Dec., pp. 78-79). This is an abridged English translation of a paper by Hohage and Schäfer published in Archiv für das Eisenhüttenwesen, 1939, vol. 13, Sept., pp. 123-125. (*See* p. 83 A).

**Anti-Piping Compounds and Their Influence on Major Segregation in Steel Ingots.** E. Gregory. (Iron and Steel Institute, 1940, *see* this Journal, Section I.). Experimental evidence has been given to show that delayed freezing of the molten steel in the feeder-head by the application of anti-piping compounds and after-teeming, exerts a marked influence on the extent and position of the major segregate in the ingot. The view is expressed that major segregation in steel is a consequence of the initial separation of the homogeneous liquid metal into two liquid phases, followed by an enrichment of one or even both of the liquid conjugates as freezing or solidification progresses.

**Billet Defects.** G. L'vov and V. Gol'deshteyn. (Stal, 1939, No. 7, pp. 24-25). (In Russian). Some results of observations on the type and causes of surface defects on billets and sheets are presented. These defects are traced back to defects in the original ingots, *e.g.*, blow-holes 1.5-2.0 mm. below the ingot surface, scale and particles of refractory material in bottom-poured ingots.

## REHEATING FURNACES

(Continued from p. 85 A)

**Calculation of Heating Time.** J. D. Keller. (Industrial Heating, 1939, vol. 6, Oct., pp. 904—916). The author develops a graphical method for the calculation of the temperature distribution in spheres in relation to the heating time. As an example he discusses the temperature distribution during the heating from 100° to 2200° F. of 12-in.-dia. mild steel spheres.

**Methods of Increasing the Throughput Capacity of Soaking-Pits.** I. Khabarov. (Stal, 1939, No. 7, pp. 21-24). (In Russian). Some experimental results are quoted and these are followed by a discussion of the means by which the heating up of cold ingots in soaking-pits could be speeded up. In one experiment the time required to heat up two cold 6½-ton ingots was reduced from 6-8 hr. to 3-4 hr. by increasing the volume of blast-furnace gas supplied to the pit, particularly in the initial stages of the heating-up process. Apart from increasing the gas supply, a correct gas/air ratio must be maintained. An increase in the size of the pits (to take eight 8-ton ingots) and other details are mentioned. More rapid heating of the ingots has the incidental advantage of resulting in reduced scaling.

**Metallurgical Furnace Plant Installed in 1939.** (Iron and Coal Trades Review, 1940, vol. 140, Jan. 19, pp. 89-93). A brief survey is presented with numerous illustrations of types of industrial furnaces supplied to British users during 1939. The types include: (a) Reheating furnaces for forgings; (b) rotary-hearth, billet-heating furnaces; (c) plate-heating furnaces; (d) town-gas-fired salt-bath installations; (e) circular soaking-pits; and (f) carburising, bright-annealing and normalising furnaces.

**Modern Slab-Heating Furnaces.** W. Trinks. (Industrial Heating, 1939, vol. 6, Oct., pp. 952-955). The author gives a detailed report on his study of the thermal efficiency of, and heat distribution in, an American slab-heating furnace. He compares the efficiencies of American and German furnaces.

**Steel Plant Furnaces—Section 3. Furnaces for Pipe and Tubes : Part III.** M. H. Mawhinney. (Industrial Heating, 1939, vol. 6, Nov., pp. 1054-1060). In the third part of Section 3 of this series of articles (see p. 85 A) on the furnaces used in steel works for the manufacture of pipes and tubes the author describes various types of annealing furnaces.

## FORGING, STAMPING AND DRAWING

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(Continued from pp. 138 A-139 A)

**The Temperature Phase in Commercial Production Forging.** W. Naujoks. (Industrial Heating, 1939, vol. 6, Oct., pp. 918-925, 987). The author emphasises the importance of the choice of suitable temperatures during the production and heat treatment of forgings. In this connection he reviews the forging and heat-treatment furnaces used in modern practice and discusses the various possibilities for their temperature control.

**Hot Forging Practice.** H. J. Bromley. (Australasian Engineer, 1939, vol. 39, Nov., pp. 78-80). After making an historical review of the development of forging, the author discusses modern methods of forging, dealing in particular with the technique of upsetting.

**Design and Construction of Metal Stamping Tools.** C. L. Szalanczy. (Iron Age, 1939, vol. 144, Dec. 14, pp. 48-51). The author gives an account of investigations carried out by engineers of the Westinghouse Electric and Manufacturing Co., who determined the most suitable types of tool steels and their optimum hardness when used for making dies for different kinds of stamping work.

**The Specification of Sheet for Deep Drawing and Pressing.** J. D. Jevons. (Sheet Metal Industries, 1939, vol. 13, Nov., pp. 1363-1364, 1367; Dec., pp. 1462, 1467-1468, 1472). After discussing the difficulties encountered in attempts to formulate specifications and recognised tests for deep-drawing quality steel sheet, the author reviews the properties which are now commonly included in specifications for sheet purchased for this particular purpose. He does this under the following headings: Grade or quality; chemical composition; method of manufacture; grain size; microstructure; and data obtained from wedge-drawing-tests, cupping, tear and bend tests. In conclusion he stresses the necessity for co-operation and goodwill between sheet manufacturers and users.

**New Wire Mill.** (Steel, 1939, vol. 105, Dec. 11, pp. 44-45, 76). The new wire mill of the Wickwire Spencer Steel Co. at Buffalo is described. The wire-drawing equipment consists of Vaughn machines, which reduce rods at speeds ranging up to 2200 ft. per min. Inasmuch as the equipment is continuous in operation, automatic electric welders are located at the entrance side of each group of machines to join the ends of the coils. (See p. 138 A).

**"Barcro" Circular-Type Non-Slip Wire-Drawing Machine.** (Wire Industry, 1939, vol. 6, Dec., pp. 755, 761). The development in the design of non-slip wire-drawing machines which led to the production of the "Barcro" CT3 9-die machine is described. It is produced in two sizes and intended for smaller sizes of iron and steel wire. The machines are manufactured at Preston, Lancashire.

## ROLLING-MILL PRACTICE

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(Continued from pp. 140 A-142 A)

**Design of Mill Stands.** P. Gruner. (Iron and Steel, 1939, vol. 13, Nov., pp. 42-45; 1940, Jan., pp. 117-121). An English translation is presented of an article on the design of rolling-mill stands which appeared in *Stahl und Eisen*, 1939, vol. 59, July 20, pp. 833-840 (*see* Journ. I. and S.I., 1939, No. II., p. 206 A).

**Synthetic Materials as Bearings for Mills.** C. D. Philippe. (Midland Metallurgical Society, Nov., 1939: Engineering, 1940, vol. 149, Jan. 26, pp. 99-100). A reproduction of an article which appeared in *Iron and Coal Trades Review*, 1939, vol. 139, Dec. 8, pp. 797-798 (*see* p. 140 A).

**Roll Neck Lubrication.** H. D. Kolb. (Blast Furnace and Steel Plant, 1939, vol. 27, Nov., pp. 1137-1140). The author comments on the systems for lubricating various types of roll necks, and reviews the properties of the lubricants applied.

**Rolling Blooms and Slabs for Maximum Tonnage Output.** T. A. Zamboky. (Blast Furnace and Steel Plant, 1939, vol. 27, Nov., pp. 1121-1125). The author points out that the sum of the energy consumed in rolling any pass with a certain maximum permissible draft, plus the roll-neck frictional losses, plus the acceleration energy must never exceed the energy delivered to the mill from the motor or engine. He develops a method which allows the calculation of the maximum permissible reduction in each pass, or the corresponding draft that will require exactly as much power as is actually available for rolling. As an example, he determines mathematically the number of passes required for rolling 28 in. wide and 4 in. thick slabs from ingots 32 in. wide and 20 in. thick using a mill of known dimensions and energy output.

**The Manufacture of High-Quality Steel Sheets at the Commonwealth Rolling Mills Pty., Ltd., Port Kembla.** (Broken Hill Proprietary Review, 1939, vol. 17, Dec., pp. 4-5). A description is given of the process and rolling-mill plant used for the production of high-quality steel sheets at the Port Kembla Works of the Commonwealth Rolling Mills Proprietary, Ltd. The mill was opened in 1939.

**The Continuous Hot-Straightening of Sheets and Hot Sheet-Straightening Machines.** P. Pfeffer. (*Stahl und Eisen*, 1940, vol. 60, Jan. 18, pp. 48-52). The author traces the development of continuous sheet-straightening machines, which are continuous in the sense that the machine is placed in the mill line between the finishing stand and the shears, and the sheets are straightened while still hot in a single pass. He discusses the advantages and dis-



advantages of having a large number of small-diameter rolls, of placing the pressure rolls either directly above or in between the straightening rolls, and describes the cooling and lubrication systems for these machines.

**A New Cold Strip-Rolling Plant is Put into Service at the Courtybella Works of Whitehead Iron and Steel Co., Ltd.** (Sheet Metal Industries, 1939, vol. 13, Dec., pp. 1431, 1438). A brief history of the Whitehead Iron and Steel Co., Ltd., from its foundation in 1903 is presented. The original cold-rolling department consisted of sixteen 8 in.  $\times$  8 in. two-high mills, disposed in four separate lines in tandem. In 1937 a four-high reversing mill for rolling strip up to 14 in. wide was installed, and in 1939 a further six four-high mills were added.

**Gauge Control for Cold Strip Mills.** F. Mohler. (Iron and Steel Engineer, 1939, vol. 16, Dec., pp. 44-56). The author enumerates the possible causes of variations in the thickness of strip produced in a cold-rolling mill. The most important of the factors mentioned are roll contour, speed of rolling, lubrication and the coolant used, as well as variations in the thickness of the incoming strip. He reviews in two separate chapters the variations in gauge at constant speed and during acceleration and retardation, and discusses the fundamental requirements of good gauge control.

**Mass Produced Cold Rolled Sections.** (Sheet Metal Industries, 1939, vol. 13, Dec., pp. 1436-1438). An illustrated description is given of the works of the Warwick Rim and Sectioning Co., Ltd., at West Bromwich. This company specialises in the cold rolling of all kinds of light sections from steel and light-alloy strip.

**Republic Completes New Tube Mill in Youngstown.** (Blast Furnace and Steel Plant, 1939, vol. 27, Nov., pp. 1141-1142). The new mill for making  $\frac{1}{2}$ -3 in.-dia. tubes by the Fretz-Moon process is described and illustrated. A description of the plant also appeared in Steel, 1939, vol. 105, Nov. 6, pp. 59-60. (see p. 141 A).

**Adaptation of the Production of Rectangular Tubes on Reducing Mills.** N. Panyushkin and S. Kamenev. (Stal, 1939, No. 7, pp. 26-34). (In Russian). A modification of the reducing tube mill which permits the rolling of rectangular-section tubes is described with detailed reference to the design of the rolls.

**Converting Worn Rolls.** W. F. Lautner. (Steel, 1939, vol. 105, Dec. 25, pp. 42, 44). The author describes the technique developed at an American sheet mill with the object of preventing the scrapping of worn rolls from the skin-pass stand. The discarded roll, which is 18 in. in dia., is annealed, turned down to 16-in. dia., and its surface is then flame-hardened using an oxy-acetylene burner head 4 in. wide. New roll necks are made, and are shrunk by the application of dry ice before being inserted into holes bored in the roll. After this reconditioning the rolls are used for applying tension in the sheet-mill train.

## HEAT TREATMENT

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(Continued from pp. 144 A-147 A)

**Recirculating Air Heating for Industrial Furnaces.** E. Stephenson, jun. (Metal Progress, 1939, vol. 36, Nov., pp. 637-641). The author describes some large and small industrial furnaces working at up to 1250° F. in which the heat is generated in one chamber and the hot gases are passed through and over the charge by a forced circulation system. He also discusses the points to be borne in mind by a purchaser of one of these furnaces. This paper has also appeared in Heat Treating and Forging, 1939, vol. 25, June, pp. 299-302, 308. (*See Journ. I. and S.I.*, 1939, No. II., p. 272 A).

**Sulphide Inclusions from Clay Packing.** G. K. Manning. (Metal Progress, 1939, vol. 36, Dec., pp. 747-748). The author mentions processing difficulties which were experienced with small carburised parts which had been packed in clay containing 0.23% of sulphur in the form of sulphate. The unsoundness proved to be due to inclusions of sulphide in the non-carburised part of the surface which had been formed by interaction with the clay.

**Flame Hardening—Its Principles and Techniques.** H. S. Card. (Industrial Heating, 1939, vol. 6, Nov., pp. 1026-1030, 1042). The author describes and illustrates different methods of surface-hardening with the oxy-acetylene flame. These include: (a) The use of a tool incorporating the burners and the quenching jets in one head, which is passed over the surface of the stationary article; (b) spinning the article to be hardened under a stationary flame with subsequent quenching; and (c) turning the article under a combined heating and quenching head while the head also moves. Method (b) is suitable for small objects and method (c) for long cylindrical bodies.

**Surface and Hardening, and Hard Surfacing.** C. P. Keogh. (Australasian Engineer, 1939, vol. 39, Nov., pp. 71-73). The author reviews the processes for producing hard surfaces on steel, dividing them into the "surface-hardening" and "hard-surfacing" processes. The former comprises the chemical or mechanical hardening of the surface, and the latter the deposition of a hard metal on a softer surface. Particular consideration is given to the flame-hardening process, and tabulated data are reproduced of the degrees of hardness obtainable by this method in steels of various compositions. The greater part of the paper deals with the welding processes suitable for creating hard surfaces on mild steel.

**The Thermal Efficiency of the Oxy-Acetylene and the Oxy/Coal-Gas Flame in Flame-Hardening.** E. Zorn. (Autogene Metallbear-

beitung, 1939, vol. 32, Nov. 15, pp. 321-327). The author reports on an investigation of the relative speeds, and degrees and depths of hardness achieved in the flame-hardening process when using oxy-acetylene and oxy/coal-gas flames on two series of steel specimens, one containing 0.38% of carbon and 0.73% of manganese and the other 0.44% of carbon and 0.65% of manganese.

**Electric Heat Treatment of Steel Parts.** Yu. M. Bogatyrev and S. A. Lagerkvist. (Vestnik Metallopromyshlennosti, 1939, No. 6, pp. 65-70). (In Russian). Results obtained using the Geveling method of surface-hardening on lathe spindles are discussed. This method, in which heat is generated by the electrical resistance between a roller and the surface of the parts being treated, eliminates all deformation of the parts. To obtain a good surface finish, a reliable contact between the roller and the surface being treated is necessary. Surface cracks may be prevented by using warm water or an emulsion as a quenching medium. If required, the changes in depth of the hardened layer arising from the mechanism of the hardening process used can be eliminated by low-temperature tempering. The depth of the hardened and transition layers may be varied within wide limits.

**The Nitriding of Steel in the Course of Quenching.** V. I. Prosvirin and A. P. Belova. (Vestnik Metallopromyshlennosti, 1939, No. 6, pp. 57-64). (In Russian). One of the authors has developed a method of nitriding which can be applied to carbon and low alloy steels. In addition to having various beneficial effects, the method renders the steels very resistant to corrosion, while the mechanical properties of quenched steel are retained. The process consists essentially in blowing a stream of gaseous ammonia on the steel while the latter is being heated to its quenching temperature. The time of exposure to the gas varies from 10-20 sec. to 1-2 hr., and it may take place, depending on the type of layer required and the size of the parts, (a) during the whole of the heating-up and holding time; (b) during the holding time only; (c) 2-3 min. before quenching; (d) at 600-700° C. and then at the holding temperature or at temperatures below the  $A_{c1}$  point. Extensive experimental results illustrating the absorption of nitrogen by steel under the above conditions, the corrosion resistance of the treated parts, the distribution of nitrogen in the layer, the strength of the nitrided layer and the behaviour of nitrided steels during tempering, are given. Carbon steels with 0.2%, 0.29%, 0.4%, 0.78% and 1.21% of carbon and several structural steels quenched from the usual temperatures and subjected to nitriding for 2-30 min. were not corroded on immersion in tap-water. Tempering did not affect the corrosion resistance. Steels nitrided and quenched were free from surface cracks and the surface layer was not brittle. The nitrogen introduced by this method was contained mainly in the solid solutions of the  $\alpha$ - and  $\gamma$ -phase, and it also counteracted the loss of hardness due to partial decarburisation on tempering.

**Production of Nitrided Crankshafts.** S. F. Yur'ev. (Vestnik Metallopromyshlennosti, 1939, No. 5, pp. 41-45). (In Russian). An extensive discussion based on experimental results is presented of the distortion of crankshafts on prolonged heating. Such distortion occurs for example, during stabilising annealing and nitriding. The machining tolerances necessary in this connection are considered. Distortion is due mainly to the action of internal stresses arising from preceding operations and to the action of the weight of the crankshaft at elevated temperatures. The effect of the formation of the nitrided layer is negligible. Distortion due to the first cause can be eliminated by employing the correct technique, by eliminating straightening operations as much as possible, and by the provision of adequate tolerances prior to heat treatment. A stabilising anneal is necessary to remove internal stresses, while distortion under the action of the weight of the crankshaft during nitriding is completely eliminated by rotating the crankshaft during nitriding and subsequent cooling. A special furnace has been designed for this purpose. In this way the sag of the axis of the shaft may be reduced to 0.05-0.10 mm. In order that the amount of the nitrided layer removed may be reduced to a minimum, final grinding of the crank pins is done between double-cone eccentric centres.

**Strain Annealing.** F. J. Robbins. (Iron Age, 1939, vol. 144, Dec. 14, pp. 33-38; Dec. 21, pp. 37-39). The author develops his theory that in the production of cold-drawn bars from hot-rolled steel, the effect of different degrees of reduction can be measured, for all general purposes, by the change in hardness which is brought about by the drawing operation. The application of this theory, which he discusses in detail, is that by a combination of the proper amount of cold drawing and an annealing treatment at low temperature (about 950° F.) bars with high strength and good ductility characteristics can be economically produced. He states that the annealing treatment can be adjusted to achieve one of the three following objects: (1) Complete relief of all stresses set up by the cold drawing; (2) a partial relief of the cold-drawing stresses; and (3) the production of heavily cold-drawn bars with tensile properties better than those of unannealed bars and not so good as those which have been heat treated. He presents numerous tables which show the results of hardness tests across sections of bars of several S.A.E. steels and relate the hardness, tensile properties and impact strength to the degree of cold reduction.

**The Influence of the Original Structure on the Results of Annealing of Chromium-Bearing Carbon Steel.** Ya. Rausin. (Stal, 1939, No. 7, pp. 41-43). (In Russian). In ball-bearing steel (carbon 1% and chromium 1.5%) and die steel the original grain size of the forgings is determined by the temperature at the end of the forging operation, while the other structural factors (pearlite grain size, thickness of the pearlite lamellae and thickness of the carbon network) are determined



by the rate of cooling of the forgings. The effect of these factors on the results of annealing was investigated. The coarser the original structure and the thicker its carbide network, the higher is the annealing temperature and the longer is the annealing time required. Annealing gives the best results with finely dispersed structures for which temperatures of 780–800° C. for about 2 hr. are necessary. This gives a structure of homogeneous fine-grained pearlite. The optimum cooling schedule (rapid cooling through the  $Ar_1$  point, which is 700° C.) is shown graphically.

**The Influence of Controlled Furnace Atmosphere in the Heat Treatment of Steel.** A. Fischer. (Machinery, 1940, vol. 55, Jan. 4, pp. 355–361). The author discusses the theory of the reactions between steel and controlled atmospheres of various compositions used for heat-treatment purposes. He shows that a reducing atmosphere, as commonly produced, is almost always a strongly decarburising atmosphere, so that it is now becoming recognised that a slightly oxidising atmosphere is much more desirable for treating the higher carbon steels in furnaces which are not provided with controlled atmospheres. By reference to the iron-carbon diagram he demonstrates the effects of changes in the  $CO/CO_2$  ratio and of the presence of hydrogen and water vapour in charcoal gas upon their decarburising action.

**New Heating Media.** D. Ya. Bushnyakov. (Vestnik Metallo-promyshlennosti, 1939, No. 6, pp. 75–79). (In Russian). The author describes the properties of molten caustic soda and caustic potash which were investigated from the point of view of their use as heating media in the heat treatment of steel. The rate of heating of cylindrical steel specimens immersed in these molten compounds and the oxidising and decarburising action of the latter are dealt with. Caustic soda has the advantage over nitrates that it does not tend to volatilise even when heated some 400° C. above its melting point. Caustic potash is more volatile. Both are rather more viscous than sodium or potassium nitrate. The rate of heating of the steel specimens increases as the temperature of the molten baths is raised. Molten caustic soda dissolves iron only to a slight extent even at high temperatures; it causes only slight superficial oxidation and does not decarburise steel. This makes it a substitute for nitrates and lead for heat-treatment temperatures below the  $Ac_1$  point. The comparatively rapid rate of attack of caustic potash on steel practically rules out its use as a heating medium.

**Modern Marvels of Electrometallurgy.** B. Stoughton. (Sixth Joseph W. Richards Memorial Lecture, Sept., 1939: Transactions of the Electrochemical Society, 1939, vol. 76, pp. 29–35). After paying tribute to the late Dr. Richards, in particular for his work in connection with the application of electric furnaces for the production of aluminium, the author briefly reviews recent applications of electric heating to metallurgical processes. The applications reviewed which concern the ferrous metals are: (1) Differential heat

treatment in which an inductive heating process can be applied to a variety of objects, *e.g.*, automobile crankshafts and armour-piercing shells, whereby one part can be made extremely hard and other parts left soft and tough; (2) pig-iron smelting in places where coke is expensive and electric energy relatively cheap; and (3) the production of refined steel in arc and in H.F. induction furnaces.

**Heat Treatment and Properties of Steel E1172: A Substitute for High-Speed Steel.** M. Pridantsev. (Stal, 1939, No. 7, pp. 35-40). (In Russian). The study had for its object the determination of the optimum composition and heat treatment of steel E1172. The effect of the maximum temperature and time of heating on the hardness and microstructure was investigated. The composition of the steels studied was within the following limits: Carbon 1.02-1.20%, silicon 1.10-2.00%, manganese 0.29-0.40%, chromium, 10.44-12.16%, vanadium 2.05-2.50%, nickel 0.17-0.25% sulphur and phosphorus each  $\leq 0.03\%$ . The optimum quenching temperature was 1240° C. for 3-5 min., which produced a hardness of Rockwell C 53-58. For single-stage tempering heating to 540-550° C. for 6-8 hr. is recommended. Three-stage tempering (8 hr. at 540° C. and two heats for 1 hr. at 540° C.) gives a somewhat greater and more uniform hardness. The retained austenite changes into martensite at below 200° C. With a carbon content near the upper limit, steel E1172 has a "hot-hardness" equal to that of high-speed steel. Some experiments carried out with samples of the steel having a higher carbon content (1.29-1.49%) showed that the retained austenite was much more stable and required prolonged tempering at 570° C. to effect its decomposition.

**Heat Treatment in the Ford New Tool and Die Shop.** E. F. Cone. (Metals and Alloys, 1939, vol. 10, Nov., pp. 326-331). At the Dearborn plant of the Ford Motor Co. it has been found advisable to centralise the tool, die and heat-treatment departments into one large tool and die shop. In this article the author describes and illustrates some of the furnaces and machinery in the new building of this department.

**Hardening and Drawing Axles at Warner Automotive Parts.** L. C. Powell. (Heat Treating and Forging, 1939, vol. 25, Nov., pp. 572-573). The author presents an illustrated description of the continuous, gas-fired, radiant-tube furnace used by the Borg-Warner Corporation for the hardening of propeller shafts and axles for automobiles. (See Journ. I. and S.I., 1939, No. II., p. 272 A).

**New Induction Method Hardens Inside Diameters.** (Heat Treating and Forging, 1939, vol. 25, Nov., pp. 541-542). A description is given of a method of applying electrical induction for the local heating and hardening of the inner surface of cylindrical bodies (see p. 147 A).

**Electric Direct Resistance Treating of Wire.** J. W. Morrison. (Iron and Steel Engineer, 1939, vol. 16, Dec., pp. 28-36). The author describes the process of electric direct-resistance heating as

applied by the Cleveland Wire Spring Co., Ohio, to the patenting, tempering and annealing of steel wire; and he gives comprehensive data concerning the physical and mechanical properties of the wire produced. The electric direct-resistance-heating equipment is fully automatic in its operation, and the cost of operation is relatively low. The heating and cooling cycles can be controlled very accurately. The wire is quenched on a rising temperature, so that the exact temperature can be selected more easily than is the case in the usual heating practice. A wire tempering unit can be converted into a patenting or annealing unit in about 2 hr. A further advantage of the method described is that in patenting, where continuous cleaning equipment is used, there is an elimination of a great deal of handling time, as all operations form part of one continuous process. Higher and more uniform physical and fatigue properties, greater impact strength and a much finer-grained structure are claimed for the wire produced by this process than for that produced by conventional methods, and, in addition, they show no surface decarburisation and are practically free from scale.

**Quenching after Hot Deformation.** D. M. Zagorodskikh. (Vestnik Metallopromyshlennosti, 1939, No. 6, pp. 71-79). (In Russian). The experiments to investigate the effect of hot deformation prior to quenching were carried out on spring steel of the following composition: Carbon 0.38%, silicon 0.34%, manganese 1.21%, sulphur 0.05%, and phosphorus 0.07%. In the experiments two test pieces were simultaneously heated to temperatures of 870-1070°C. One of the test pieces was then forged down some 50% by a single blow (without change in temperature), and both were then quenched together in water at 15°C. It was found that the average hardness of all deformed test pieces was less than that of the unforged ones. The microstructure of quenched forged test pieces consisted of finer acicular martensite than that of undeformed specimens. In addition, the former showed troostite inclusions. There was no difference in the Debye X-ray diagrams.

**The Heating and Liquid Quenching of Massive Sections.** J. A. Duma. (Heat Treating and Forging, 1939, vol. 25, Sept., pp. 505-508). In the concluding part of this paper (see p. 23 A) the author describes the sequence of operations in the heat treatment when hardening round steel bars 4, 8, and 16½ in. in dia., with special reference to the holding times and quenching temperatures. He presents a number of curves showing the respective cooling rates of these sections.

**Austempering and Hardenability.** J. M. Robertson. (Iron and Coal Trades Review, 1940, vol. 140, Jan. 19, pp. 94-97). The author discusses the mechanism of the intermediate change in the cooling of steel during the process of heat treatment now well known as "austempering" (see Journ. I. and S.I., 1939, No. II., pp. 94 A and 341 A). To obtain this change in carbon steels, it is necessary

to quench in media that are held above the upper limit of the martensite range and below the temperature at which austenite transforms with maximum velocity into pearlite. Furthermore, it is necessary that the cooling power of the quenching medium must be such in relation to the size of the specimen and the maximum rate of its austenite  $\rightarrow$  pearlite transformation that this transformation is prevented. In practice, austempering of carbon steel cannot be applied to large objects, because, as the size increases, the temperature of the medium must be lowered in order to suppress the formation of pearlite. The addition of alloying elements in suitable amounts and combinations reduces the rate of formation of pearlite and makes it possible to suppress this change in large specimens. But alloying elements also decrease the rate of formation of primary troostite, and the amount added must be restricted, or the time required for austempering will become too long for commercial application. The author also quotes the findings of Gensamer, Pearsall and Smith relative to the mechanical properties of austempered steel (*see* p. 48 A) and demonstrates that these are not in agreement with the conclusions of Griffiths, Pfeil and Allen (*see* Journ. I. and S.I., 1939, No. I., p. 374 A); he believes that while there may be an intrinsic difference between steels of different composition, it is more likely to be due to the exact conditions under which the intermediate change occurs, and the subject is one which calls for further study by metallurgists.

**Austempering in Successful Commercial Operation.** (Heat Treating and Forging, 1939, vol. 25, Oct., pp. 499—503). An illustrated description is given of the plant and sequence of operations employed for the austempering of small parts at the works of the American Steel and Wire Co. (*See* p. 24 A and Journ. I. and S.I., 1939, No. II., p. 94 A).



## WELDING AND CUTTING

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(Continued from pp. 148 A-152 A)

**The Prevention of Acetylene-Air Explosions by Additions of Carbon Dioxide or Nitrogen.** W. Gliwitzky. (Autogene Metallbearbeitung, 1940, vol. 33, Jan. 1, pp. 2-5). The author gives an account of an investigation carried out at the Chemisch-Technische Reichsanstalt in Berlin in order to determine the quantities of carbon dioxide or nitrogen required to dilute acetylene-air mixtures of various proportions to such an extent as to make explosions impossible.

**A Note on the Pressures Occurring in Acetylene-Oxygen Mixtures.** W. Gliwitzky. (Autogene Metallbearbeitung, 1940, vol. 33, Jan. 1, pp. 5-6). The author gives an account of the pressures determined in 5.4 litre and 84 litre bombs during the explosion of acetylene-air mixtures of various proportions.

**Factors Governing the Arc Welding Behavior of Mild Steel Wire.** J. C. Joubanc. (Wire and Wire Products, 1939, vol. 14, Dec., pp. 697-698). The author reports on some investigations undertaken to establish, if possible, a relationship between the manufacturing characteristics of mild steel wire and the welding characteristics of the wire when used as an electrode. The results led to the following conclusions: (1) There is less arc disturbance when welding with soft steel electrodes than when hard-drawn wire is used; (2) the sulphur in the steel should be kept very low as it causes "spattering"; (3) contrary to general opinion, the addition of copper to the steel has no deleterious effect; and (4) when the molten metal has a high surface tension it is transferred across the arc in large globules which causes "spattering." With regard to conclusion (4), the author refers to Doan's experiments which showed that the application of a thin coating of a suspension of antimony in sodium silicate caused a marked decrease in the surface tension of the molten metal, and this was attended by a marked increase in the stability of the arc.

**Note on the Use of Single-Run Mild Steel Electric-Arc Weld Metal, Showing that Excellent Mechanical Properties are Obtainable.** (British Engine Boiler & Electrical Insurance Co., Ltd., Technical Report for 1938, pp. 39-46). A report is presented on the results of tensile and Izod tests on weld metal cut from joints made in  $1\frac{1}{2}$  in.-thick plate electrically welded by a single run and by a multiple run. These results show that the presence of a dendritic or columnar structure is insufficient in itself to condemn a weld and that the quality of unrefined metallic-arc weld metal may vary

enormously. It is therefore necessary to discriminate between different classes of metal.

**Manganese in Rutile Type of Coated Steel Electrodes.** E. G. Enck. (Welding Journal, 1939, vol. 18, Nov., pp. 436-S-440-S). The author reports on his investigation of the influence of ferro-manganese, and of manganese in other forms, in the coating of welding electrodes on the manganese content and other properties of the deposited weld metal. The coating mixtures used in the tests were rutile (a form of titanium dioxide), cellulose, clay, asbestos, sodium silicate and ferro-manganese. He found that : (1) Increasing the amount of ferro-manganese in the coating increased the amount of manganese in the weld, but had very little effect on the carbon and silicon contents ; (2) the shape of the weld bead was not governed by the composition of the metal, but was probably controlled either by the surface tension of the slag or by the " interfacial tension " of the slag and weld metal ; and (3) even when the percentage of ferro-manganese in the coating was reduced, it was possible to increase the manganese content of the weld metal by increasing the content of organic matter or by adding potassium silicate to the coating mixture.

**Jig for Resistance Welding of Thin Gage Stainless Steel Tubing.** W. T. Barker and A. R. Walker. (Welding Journal, 1939, vol. 18, Nov., pp. 417-S-420-S). The authors describe the constructional details of a jig for use in the manufacture of seam-welded tubes of thin stainless steel sheet. This jig can be used for tubes of any length by introducing the lower electrode into the tube through the unwelded lap behind the electrodes. They also discuss the optimum welding conditions for the electric resistance welding, *i.e.*, the amperage, the mechanical pressure and the duration of the current flow. The results of some torsion, bend and compression tests on specimens of welded and riveted tubes are compared. The jig was designed and tested at California University.

**Welding in the Manufacture of Valves for High Pressures and Temperatures.** W. F. Crawford and L. H. Carr. (Welding Journal, 1939, vol. 18, Nov., pp. 713-722). The authors give an account, with numerous illustrations and diagrams, of the applications of electric and oxy-acetylene welding in the construction of forged and cast steel valves for service at high temperatures and pressures. Particular reference is made to the deposition of a chromium-tungsten-cobalt alloy to form the valve seat as this material maintains a high hardness at high temperatures.

**Reaction Chambers.** (Steel, 1939, vol. 105, Dec. 18, pp. 51-52). The fabrication of reaction chambers for petroleum cracking at temperatures of about 920° F. and a pressure of 350 lb. per sq. in. is described. The material used is Lukens Thermel steel, a molybdenum-bearing steel meeting the requirements of the A.S.T.M. Specification A-204-38. Each vessel is 8 ft. in dia. and 50 ft. long, and they weigh about 53 tons each. The minimum thickness of the

shell and end plates is  $1\frac{13}{16}$  in. Particulars are given of the welding procedure and the subsequent stress-relieving treatment applied in the manufacture of these vessels.

**The Application of Welding for Repair Work in Machine Shops and Iron Works.** F. H. Müller and Z. L. Zeyen. (Technische Mitteilungen Krupp, Technische Berichte, 1940, vol. 8, Jan., pp. 1-22). The authors describe and discuss the application of electric welding for the repair of worn, cracked or broken castings and equipment; they quote numerous examples of successful repairs carried out in the course of several years' experience with electric welding at Krupp's works.

**Welding Tungsten Steels.** W. Spraragen and G. E. Claussen. (Welding Journal, 1939, vol. 18, Nov., pp. 430-S-435-S). The authors review the literature to July 1937 on the welding of tungsten steel. A bibliography of 83 references is appended.

**The Welding of Chromium-Molybdenum Steel Tubes.** P. Wimmer. (Autogene Metallbearbeitung, 1939, vol. 32, Dec. 15, pp. 345-352). The author reports on the investigation of the properties of oxy-acetylene welded joints in chromium-molybdenum steel tubes the composition of which fell within the following limits: Carbon 0.23-0.33%, silicon 0.24-0.28%, phosphorus 0.010-0.015%, sulphur 0.015-0.035%, manganese 0.57-0.64%, chromium 0.95-1.04% and molybdenum 0.21-0.23%. The welding rods used included a low-carbon unalloyed steel, a steel containing 0.85% of nickel and one containing carbon 0.28%, chromium 1.02% and molybdenum 0.25%. The results of hardness surveys and tensile tests together with micrographs of the structures are presented. The investigation proved that the best quality welds were obtained with the filler rod containing nickel.

**Welding and Cutting of Stainless Clad Steel.** W. B. Keelor. (Welding Journal, 1939, vol. 18, Nov., pp. 723-725). The author describes the correct technique for the electric and autogenous welding of joints in stainless-clad steel plates, *i.e.*, mild steel plates coated with a layer of 18/8 stainless steel of a thickness equal to one-fifth of that of the composite plate.

**Showing How the Microstructure of a Part Welded by the Metallic Arc may be Affected by a Comparatively Small Change in a Heat Treatment.** (British Engine Boiler & Electrical Insurance Co., Ltd., Technical Report for 1938, pp. 29-38). A series of tests on the effect of different cooling processes applied in the heat treatment of metallic-arc-welded steel boiler-plate is described. The results obtained show that after heat treatment at 600° C., or slightly higher, and cooling slowly in the furnace to room temperature, the precipitation of nitride needles commences at about 350° C. and has visibly increased when 280° C. is reached. If, on the other hand, the steel is removed from the furnace at a temperature in the 300-400° C. range and cooled in air or quenched in water, then no nitride precipitation takes place.

**Welded Structures in some Cast and Wrought Steels.** J. W. Bolton and A. J. Smith. (Welding Journal, 1939, vol. 18, Nov., pp. 398-S-417-S). The authors report in detail on the effects of pre-heating on the microstructure and hardness of welded joints of both similar and dissimilar plain and alloy steels. The specimens were prepared from solid bars  $2\frac{1}{2}$  in. in dia. butt-joined mechanically by a small screw in the centre; a U-shaped groove was cut to receive the weld and the assembly was placed in two furnaces one on each side of the joint. Thermocouples were attached so that the temperatures before and during the welding could be read. The materials used were cast and wrought steel containing carbon from 0.19% to 0.41% with and without small additions of molybdenum, chromium and nickel.

**The Tempering of Autogenous Welds by Recrystallisation.** G. Czternasty. (Autogene Metallbearbeitung, 1940, vol. 33, Jan. 15, pp. 17-25). Although it is well known that autogenous welds can be tempered it has been practically impossible to obtain a perfectly even degree of grain refinement in such welds. The author reproduces Hanemann's recrystallisation diagram which shows the relation of the grain size of soft iron (0.05% of carbon) to the percentage of deformation at different temperatures, and by reference to this he explains the reasons for the failure of various methods of grain refinement discussed in the first part of the paper. In conclusion he describes an investigation of the tensile, bend and impact strength of welded specimens of 15-mm.-thick boiler steel after different kinds of treatment for grain-refining; the data obtained show that a process of hot deformation by rolling with subsequent normalising produced the desired results.

**Shrinkage and Other Initial Stresses in Welds.** M. F. Sayre. (Welding Journal, 1939, vol. 18, Nov., pp. 393-S-397-S). On the basis of an analysis of the published cases of the failure of welded joints due to cracking, the author discusses the conditions under which this type of failure occurs. He finds that there are five kinds of failure attributable to thermal effects. These are: (1) Cracks which occur while the metal is still at a red or white heat; (2) cracks which apparently occur below the transformation temperature and within the "blue-brittle" range; (3) cracks connected with the formation of martensite; (4) failures arising from the shape of the pieces being welded; and (5) failures occurring some time after the welding which are probably due to a combination of the locked stresses and the stress imposed by an applied load. He considers each of these failures in turn.

**The Determination of the Strength of Fillet Welds by Fatigue Tests.** A. Thum and A. Erker. (Zeitschrift des Vereines deutscher Ingenieure, 1939, vol. 83, Dec. 23, pp. 1293-1297). This investigation concerns the strength of T-joints between steel plates made with two fillet welds by the electric welding process, and its object was to determine the weld thickness/plate thickness ratios at which frac-



ture caused by alternating bend tests would occur : (1) at the weld metal/base metal interface, and (2) in the weld metal itself. The authors describe the testing apparatus and procedure in detail. They find that there is a critical value of the ratio  $wt/pt$  (where  $wt$  and  $pt$  are the thicknesses of the weld and plate respectively) at 0.2, above which the fracture will generally take place at the interface, and below which it will occur in the weld metal. On the basis of the data obtained the authors develop a method of calculating the fatigue strength of welded T-joints in steel plates.

**The Causes of Cracks in Welded Aircraft Steels.** O. Werner. (Welding Journal, 1939, vol. 18, Nov., pp. 425-S-428-S; Welding Industry, 1940, vol. 7, Jan., pp. 424-427). This is an abridged English translation of the author's report on the causes of fissure formation in oxy-acetylene-welded steel sheets used for constructing aeroplanes. The original paper appeared in *Archiv für das Eisenhüttenwesen*, 1939, vol. 12, Mar., pp. 449-455 (see *Journ. I. and S.I.*, 1939, vol. II., p. 96 A).

**Contribution to the Study of the Metallurgy of Oxy-Acetylene Cutting.** D. Séférian. (*Revue de la Soudure Autogène*, 1939, vol. 31, Oct., pp. 788-792). In this study of the metallurgical effects produced by the oxy-acetylene cutting process on steel, the author presents a number of curves showing the relationship between the temperature attained at different distances from the cut and the thickness of the material. He discusses the depth of the transformation zone and illustrates how the structure of steels of different composition is affected by the cutting process. In conclusion he presents a tabular summary showing the influence of various percentages of carbon, manganese, silicon, phosphorus, nickel, chromium, molybdenum, aluminium, tungsten, vanadium and copper on the operation of cutting as well as on the properties of the steel after cutting.

**Preparing Mild Steel Plates for Welding by Means of Flame-Cutting.** (British Engine Boiler and Electrical Insurance Co., Ltd., Technical Report for 1938, pp. 17-28). An account is given of an investigation made to determine whether the preparation of the edges of steel plate for welding by a hand- or machine-operated oxy-acetylene torch had any detrimental effect on the quality of the welded joint. Specimens of mild-steel boiler plate 1 in. thick were used. The experiments showed that, with a suitable flux covering on the rod, the scale produced by flame-cutting can be efficiently floated off during welding, and that the hardness of the welded edge of the plates is not necessarily increased by virtue of its having previously been flame-cut. With flame-cutting by hand the edge is much more irregular than when a machine-driven torch is used, but it was found that this had no detrimental effect on the quality of the weld. It is recommended that all loose scale should be removed before flame-cut edges are welded.

## MACHINING

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(Continued from p. 94 A)

**A New Cutting Alloy.** (Machinery, 1940, vol. 55, Jan. 11, pp. 397-398). The production is briefly described of "Kennametal" the essential component of which is the compound  $WTiC_2$ . It is said to differ in its physical properties from cemented tungsten carbide in that it has greater strength, lower frictional resistance and lower thermal conductivity. The new material is intended for machining steels of a wide range of hardness as well as many non-ferrous metals and alloys. It is claimed that, using tools tipped with Kennametal, alloy steels of hardness up to 682 Brinell can be machined at a surface speed of from 20 to 30 ft. per min. The most general application, however, is for the machining of steels of about 350 Brinell hardness which can be cut at surface speeds exceeding 100 ft. per min. The application of Kennametal for shell and tube turning is briefly discussed.

**Free-Cutting Steel Containing Lead.** R. Hanel. (Metallwirtschaft, 1939, vol. 18, Sept. 15, pp. 789-791). The author reviews the results obtained by Robbins (*see* Journ. I. and S.I., 1939, No. I., p. 107 A) when studying free-cutting steel containing lead.

**Laboratory Test for Machinability.** A. S. Kenneford. (Engineering, 1939, vol. 148, Oct. 27, pp. 485-486). The author describes the Oxford-Airey machinability tester and the results of some tests made with it on alloys varying in machinability from the free-cutting magnesium alloys to Monel metal. The effect of carbon contents in the range 0.1-1.07% on the machinability of forged steel was also investigated.

**Control in Modern Gear Manufacture.** R. S. Marthens. (Iron Age, 1939, vol. 144, Dec. 21, pp. 33-36). The author outlines the methods which are used for controlling the dimensions of finished gear parts, and reviews the qualities and the heat treatment of the materials used for gears. Operations in the machining of housings for enclosed gear drives are also described.

**Investigation of the Connection Between Surface Smoothness and the Feed when Finish-Turning Cast Iron.** G. A. Preys. (Vestnik Metallopromyshlennosti, 1939, No. 5, pp. 71-73). (In Russian). Results obtained from profilograms of turned cast iron surfaces are plotted giving a curve relating the feed to the amplitude of the "hill and dale" roughness of the surface.

## PROPERTIES AND TESTS

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(Continued from pp. 158 A-163 A)

**Research in the Iron and Steel Industry.** (Iron and Coal Trades Review, 1940, vol. 140, Jan. 26, pp. 187-189). A brief review of the various phases of research conducted under the aegis of the Iron and Steel Industrial Research Council.

**The Physics of Metals. VII.** P. Malaval and P. Bernard. (Mémorial de l'Artillerie Française, 1939, vol. 18, No. 71, pp. 465-493). In the first chapter of this, the last paper of a series (*see* p. 38 A), the authors review the modern theories on elasticity and plasticity. In the second chapter the mechanical properties of metals in the crystalline state are outlined and reference is made to ageing and recrystallisation phenomena and to the theoretical basis of annealing and of the solidification of castings.

**The Bending-Tensile Test—A New Method of Testing Metallic Materials.** E. Mohr. (Zeitschrift des Vereines deutscher Ingenieure, 1940, vol. 84, Jan. 20, pp. 49-52). The principles of the bending-tensile test are described by the author. This method of testing gives valuable data as to the deformation properties of sheet metal. The specimen is held in a vertical position and a static tensile stress is applied by a suitable device at the lower end. The specimen passes between horizontal parallel rollers about half-way up the strip and alternating-bend stresses are applied to the upper end of the strip so as to bend it through an angle of  $10^\circ$  from the vertical over each roller alternately. Graphs are prepared by plotting the number of reversals necessary to cause fracture against different static loads. The author gives some examples of these curves for non-ferrous metals and alloys and discusses their interpretation. (*See* Journ. I. and S.I., 1938, No. II., p. 162 A).

**An Investigation of the Internal Stresses in Cast Iron.** J. E. Hurst. (Iron and Steel, 1939, vol. 13, Oct., pp. 29-32; Nov., pp. 61-64; 1940, Jan., pp. 133-134). The author explains a method of calculating the internal stresses in cast-iron piston rings and cylinder liners. The method is based on the measurement of the extent of movement of a gap cut in rings machined from the casting under examination. The diameter, breadth and thickness of the test ring are accurately measured and the ring is carefully clamped in a vice. In this restrained position a gap is carefully cut and measured. The ring is then freed from the vice and the gap is again measured in the free position. The actual magnitude of the stress can be calculated from the formula :

$$f = \frac{EtW}{4\pi r_1 r_2}$$

where  $f$  is the stress in tons per sq. in.,  $E$  the modulus of elasticity,  $t$  the thickness of the ring in inches,  $W$  the amount by which the gap has opened in inches, and  $r_1$  and  $r_2$  are the radii of curvature in the free and restrained positions respectively. In the second part of the paper the author compares the effects of different heat treatments on the internal stress of different qualities of piston rings, and points out that further investigation is necessary to distinguish between internal stress conditions brought about during crystallisation, by the change from the liquid to the solid state, and by changes in the solid state.

**Causes of "Layer Formation" in the Fracture of Structural Steels.** I. Golikov and P. Karyazin. (Stal, 1939, No. 7, pp. 44-51). (In Russian). "Layer formation" in the bending and impact fractures of a large number of structural chromium-nickel steels was studied, the results being illustrated by numerous macrographs and micrographs. The influence, in this connection, of various heat treatments was also investigated. The general conclusion arrived at is that the phenomenon of "layer formation" is not the result of any pre-existing defect in the metal, but that it occurs actually during fracture. It is due to differences in the properties of different fibres of the steel. These differences are particularly marked after quenching and after low-temperature tempering. As a result of these differences, some of the fibres in bending are still undergoing plastic deformation, while the others are already fractured. This results in one group of fibres slipping over the other and thus gives rise to the characteristic appearance of the fracture. The differences in mechanical properties between the fibres are due to differences in chemical composition, which in turn are caused by primary dendritic heterogeneity.

**Failure of Press Tools under Fatigue and Impact.** C. E. Bretney. (Metal Progress, 1939, vol. 36, Dec., pp. 751-754). The author discusses the effect of the surface condition of press tools on their fatigue strength, and he emphasises, in particular, the deleterious influence of small marks, scratches and notches. In the second part of the paper he discusses the relation between the heat treatment and the impact strength of tool steel, and points out the importance of the ratio of impact value to hardness.

**Industrial Gears for Large Transmissions.** E. J. Wellauer. (Metal Progress, 1939, vol. 36, Dec., pp. 725-730, 778). The author reviews the requirements for high-speed gears for heavy power transmission purposes, in particular for rolling-mill drives and reduction units between steam turbines and propeller shafts. He discusses the various causes of failure and how they can be controlled, *viz.*, wear, pitting, spalling, rolling, and plastic deformation. The greater part of the paper is devoted to a comparison of the relative merits of cast iron and plain and alloy steels for both forgings and castings; and full data of the physical and mechanical properties of forged and cast gears of various compositions are presented.



**Fatigue Problems in Structural Designs.** A. V. Karpov. (Metals and Alloys, 1939, vol. 10, Nov., pp. 346-352). The author points out that engineers are now paying more attention than formerly to the fatigue strength of structural steel when designing members of structures. In this connection he develops a time-stress diagram which relates the fatigue strength to the ultimate strength of a material and enables a designer to apply proper safety factors based on a combination of fatigue and tensile tests results.

**The Detection of the Fatigued Zone by a Corrosion Method.** T. Nishihara and M. Kawamoto. (Transactions of the Society of Mechanical Engineers, Japan, 1939, vol. 5, Aug., pp. 43-50). (In Japanese). The authors report on their investigation by the examination of etched steel specimens of the spread of the fatigue-affected areas of steel at various stages of testing.

**Relation between the Speed of Strain and the Deflection Due to Internal Friction of Metals.** T. Nishihara, Y. Sawaragi and Y. Taga. (Transactions of the Society of Mechanical Engineers, Japan, 1939, vol. 5, Aug., pp. 34-43). (In Japanese). The authors report on an investigation in which they endeavoured to determine the amount of energy consumed by internal friction in the fatigue-testing of specimens of electron, brass and steel. They also established a relationship between the amount of hysteresis energy absorbed and the amount of horizontal deflection.

**The Damping of Cast Iron, with Special Reference to Cast Crankshafts.** J. Geiger. (Giesserei, 1940, vol. 27, Jan. 12, pp. 1-9; Jan. 26, pp. 30-32; Mitteilungen aus den Forschungsanstalten des Gutehoffnungshütte-Konzerns, 1939, vol. 7, Dec., pp. 215-231). The author discusses various methods of determining the damping properties of cast iron and describes a testing machine developed by himself for measuring and recording the damping capacity of cast-iron test pieces. With this machine he undertook an investigation with the object of determining the relationship between the structure of cast iron and its damping capacity as well as the composition of an iron with good casting properties, high strength, low notch-sensitivity and high damping capacity. The data he obtained led to the following conclusions: (1) The damping capacity of an unused specimen is much greater than that of a specimen which has been previously subjected to stress reversals, and a final and constant value is approached after about 200,000 reversals. (2) In comparing the damping capacities of different qualities of cast iron it was found that, as a rule, the lower the strength and the shear modulus the higher was the damping capacity. (3) The damping capacity of a cast iron crankshaft was from 80% to 150% greater than that of a steel one, the increase depending on the quality of the iron used.

**Improved Method of Determining the Hardness of Steel Wire on a Rockwell Machine.** A. V. Tarnovskiy. (Zavodskaya Laboratoriya, 1939, No. 4-5, pp. 475-479). (In Russian). The results of a series of hardness tests on quenched and tempered chromium

steel wire show that considerable errors are caused partly by structural heterogeneity of the wire, due to heat-treatment effects as well as by slight changes in the test conditions. A modified table for the Rockwell hardness testing machine is recommended. It was also necessary to provide the wire specimen with two plane parallel faces for the hardness tests described.

**Chrome Hardening.** (Automobile Engineer, 1939, vol. 67, Dec., pp. 453-454). Some particulars are given of the results of wear tests on automobile engine cylinder bores which show the great reduction in wear which is attained by having an extremely thin deposit of chromium on the cylinder wall. The "Van der Horst" and "Listard" methods of chromium-hardening are mentioned.

**Magnetic Materials for Transformers, Especially Transformers for Meters.** H. H. Meyer and H. Fahlenbrach. (Technische Mitteilungen Krupp, Technische Berichte, 1939, vol. 7, Nov., pp. 123-132). After a brief mathematical discussion in which it is shown how the efficiency of transformers depends largely on the magnetic properties of the alloys used in their construction, the authors discuss the magnetic properties of the Krupp "Hyperm" steels which include both iron-silicon and iron-nickel alloys. They present a comprehensive table of the specific gravity, magnetic properties and applications of the "Hyperm" alloys 0, 1, 2, 3, 4, 5, 6, 20, 36, 40, 50, 702 and 766. The firm of Krupp claims to have developed a method of heat treatment which imparts to a 36%-nickel alloy a degree of magnetic permeability hitherto only possible with a 50%-nickel alloy.

**An Apparatus for Determining Thermomagnetic Behaviour of Slags, and some Preliminary Results Obtained with It.** B. A. Rogers and K. O. Stamm. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1133: Metals Technology, 1939, vol. 6, Dec.). The authors describe a convenient apparatus which they developed for determining the magnetic behaviour at high temperatures of open-hearth slags and metal oxides. The apparatus is a modification of that used by Curie, and its design is based upon the fact that if a ferromagnetic substance such as a slag is placed in a non-uniform magnetic field it experiences a force that tends to move it into the region of maximum field strength. The authors discuss the results obtained with this apparatus on specimens of ferric oxide, natural magnetite and wüstite at temperatures up to 900° C.

**Metallographic Determination of Ferro-Magnetic Phases.** H. S. Avery, V. O. Homerberg and E. Cook. (Metals and Alloys, 1939, vol. 10, Nov., pp. 353-355). The authors describe their method of discovering magnetic constituents in a non-magnetic matrix. They cover the polished surface of the specimens to be examined with a very dilute colloidal solution of magnetic particles and apply a magnetic field, which causes a concentration of the colloid over the magnetic areas. This concentration is visible under the microscope

as a characteristic mosaic pattern. The method has proved especially useful for the detection of ferrite in austenitic nickel-chromium-iron alloys and manganese steels. Micrographs showing typical results for three different alloys are reproduced.

**Heat Capacity of Iron Carbide from 68° to 298° K. and the Thermodynamic Properties of Iron Carbide.** H. Seltz, H. J. McDonald and C. Wells. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1137: Metals Technology, 1939, vol. 6, Dec.). Using a specially prepared sample of steel containing known weights of the carbide  $\text{Fe}_3\text{C}$  and of iron, the authors determined the specific heat of the carbide at a number of temperatures in the range 68–298° K. From the data thus obtained and using four Debye functions for extrapolation, they calculate the entropy of the carbide to be 25.7 with an accuracy of  $\pm 1$ .

**The Thermal Conductivity of Metals and Its Influence on the Heat Exchange.** R. von Linde. (Metallwirtschaft, 1939, vol. 18, Dec. 29, pp. 1053–1055). Data for the thermal conductivity of various ferrous and non-ferrous alloys are given, and the author points out that the importance of the thermal conductivity of the walls of interchangers and other plant is over-estimated.

**Creep of Some Chromium-Molybdenum Steels.** H. D. Newell. (Metals and Alloys, 1939, vol. 10, Nov., pp. 342–345). The author reports on a joint investigation by the Allegheny Ludlum Steel Corporation, the Babcock and Wilcox Tube Co. and the Climax Molybdenum Co., the object of which was to determine whether the creep-resisting properties of steel containing 4–6% of chromium and 0.5% of molybdenum would be improved by increasing the amount of the latter element to 1.5%. The method of testing employed enabled the stresses which would produce creep rates of 0.01% and 0.10% in 1000 hr., 1% in 10,000 hr. and 1% in 100,000 hr. at temperatures of 1000°, 1100° and 1200° F. to be determined. The results indicated that the steels containing 1% and 1.5% of molybdenum are slightly more resistant at 1100° and 1200° F. to creep than 0.5% molybdenum steel, but the improvement is not sufficient to justify the additional cost.

**Heat-Resisting Alloys.** W. H. Hatfield. (Midland Metallurgical Societies, Oct., 1939: Journal of the Metallurgical Society, 1939, vol. 19, Dec., pp. 155–163). In this general outline of the properties of heat-resisting steels, the author presents some tables of the analyses, scale-formation and strength properties of these alloys and describes some long-time creep tests of an unusual nature which are being conducted at Sheffield.

**A Preliminary Study of Gases in Cast Iron.** W. Y. Buchanan. Institute of British Foundrymen: Foundry Trade Journal, 1939, vol. 61, Dec. 21, pp. 423–424; Dec. 28, pp. 443–446). After surveying the literature on the subject of gases in cast iron and steel, the author mentions some general causes of the occurrence



of gas holes in iron castings, such as the permeability of the sand being too low and the incorrect drying of cores. He thus considers the particular case of gas which is brought to the mould dissolved in the cast iron itself and is likely to come out of solution during solidification. He describes the cast-iron bell and the apparatus used for collecting the gases evolved from molten iron, presents some tables of analyses of the gases evolved and of the cast iron and discusses the effects of additions of ground rust, aluminium alloy scrap, mill scale and soda ash on the rate of evolution and the composition of the gases.

**Gas Content Vs. Steel Behavior.** G. T. Motok. (Iron Age, 1939, vol. 144, Nov. 30, pp. 25-28; Dec. 7, pp. 40-43). After describing some of the effects attributed to the presence of oxygen, hydrogen and nitrogen in steel, the author describes the principles of the method adopted in the research laboratories of the Republic Steel Corporation to determine, by vacuum-fusion technique, not only the total quantity of the gases in a sample of steel, but also in what form the oxygen is distributed. The author then cites a number of cases in which samples of steel of similar analyses as to carbon, silicon, manganese, sulphur and phosphorus, but with different physical characteristics, were examined by the above method and he relates their individual characteristics to the presence of certain oxides.

**Properties of Cast Iron with Titanium and Boron Additions.** P. Bastien. (Bulletin de l'Association Technique de Fonderie, 1939, vol. 13, Aug.-Sept., pp. 276-292). **Cast Iron Containing Cobalt and Cerium.** L. Guillet, jun. (Bulletin de l'Association Technique de Fonderie, 1939, vol. 13, Aug.-Sept., pp. 292-300). These two papers contain the information published jointly by the authors in I. and S.I., Carnegie Scholarship Memoirs, 1938, vol. 27, pp. 77-143. (See Journ. I. and S.I., 1939, No. II., p. 224 A).

**A Note on Wear-Resistant Nickel-Bearing Steels and Cast Irons.** (Centre d'Information du Nickel, Applications du Nickel, 1939, Series X, No. 13, pp. 3-12). A review is given of the compositions and main properties and uses of the following wear-resisting nickel-bearing steels, and cast irons: (a) Case-hardened nickel and nickel-chromium steels, (b) hard and medium-hard nickel and nickel-chromium steels, (c) self-hardening nickel-chromium steels and (d) die-castings and austenitic and nickel-chromium cast-irons. The paper contains numerous illustrations showing articles made from the alloys discussed, in particular mining and grinding equipment.

**Welded Carbon-Molybdenum Steel Plate for Oil Refinery Reaction Chambers.** (Alloy Metals Review, 1939, vol. 2, Dec., pp. 86-88). A detailed account is presented of the properties of a low-alloy steel plate containing carbon 0.21% max., manganese 0.50-0.90% and molybdenum 0.40-0.60%, which was used for the manufacture of two reaction chambers for an oil refinery. These vessels



are 50 ft. long and 8 ft. outside dia. and are to be operated at 920° F. and 350 lb. per sq. in.

**Nickel-Clad Steel.** (Mond Nickel Co., Ltd., Bureau of Information on Nickel, 1939, Publication CC 1). In this pamphlet the properties and fabrication of nickel-clad steel are outlined under the following headings: Strength of the bond; properties; corrosion resistance; cold-working; annealing for cold pressing; heating for hot-working; surface cleaning; and joining. In the last paragraph an illustrated account is given of the procedures for electric welding, autogenous welding and riveting nickel-clad steels.

**Examination of a Test Bar of the Sixteenth Century.** R. Mailänder and H. Hiltenkamp. (Technische Mitteilungen Krupp, Technische Berichte, 1939, vol. 7, Nov., pp. 139–141). The authors present the results of physical, chemical and metallurgical tests carried out in Krupp's laboratories on an iron bar, 35 × 15 mm. in section, submitted to them by a Copenhagen museum. This bar was recovered from a wreck during dredging operations in the Cattegat in 1937, and there was good evidence to show that it was made in England in the period 1575–1600. The bar exhibited very uneven hardness and elongation characteristics.

**British Standard Specification for Round Strand Steel Wire Ropes for Lifts and Hoists.** (British Standards Institution, No. 329–1939).

**British Standard Specification for Steel Tubes for Water Well Casing.** (British Standards Institution, No. 879–1939). This standard specification has been prepared under the authority of the Mechanical Industry Committee in response to a request received from the War Office. It applies to lapwelded and weldless steel tubes for water well casing, of nominal sizes 4 in. to 48 in., having butting joints of the following types: (a) Screwed and socketed, (b) screwed flush, inside and outside.

## METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 164 A-165 A)

**Progress in Steel Metallurgy During the Last Ten Years.** W. H. Hatfield. (Metallurgia, 1939, vol. 21, Dec., pp. 33-35). The author reviews the advances made in steel metallurgy during the last decade. In the first part of his paper he deals with the progress due to the application of science to metallurgical problems. The advances in the knowledge of a number of ferrous systems is indicated and the application of some new physical methods to the examination of steel is briefly referred to. In the second part of the paper improvements in the properties of various steels are discussed and classified into those brought about by: (a) Change of manufacturing process, including melting and forging procedures, heat treatment and surface treatment, and (b) change of composition.

**Tschernoff's Centenary.** N. T. Belaiew. (Metal Progress, 1939, vol. 36, Dec., pp. 744-747). The author gives an account of the life and work of Dimitry Tschernoff, the Russian metallurgist, who as early as 1868 discovered two critical points  $a$  and  $b$  for steel, which later proved to be identical with Osmond's  $A_1$  and  $A_3$  points.

**The Detection of Defects in Steel Parts by the Magnetic Powder Method.** A. V. Zhigadlo. (Zavodskaya Laboratoriya, 1939, No. 4-5, pp. 438-448). (In Russian). Observations made in tests on aircraft parts by the magnetic powder method are dealt with. The object of the investigation was to determine the sensitivity of the method in detecting defects of various shapes and size, both on and below the surface. The methods employing residual circular magnetisation (induced by passing an instantaneous direct or alternating current through the parts) and an external field (produced by either direct or alternating current passed through the parts or by an electromagnet) were studied from the above point of view using parts with natural and artificial defects. In the former case, the defects detected were marked and the parts were then sectioned and examined microscopically. A considerable amount of data concerning the sensitivity of the different methods is given in tabular form. In the method in which an external electromagnet was used it was observed that the results may be masked by magnetic effects due to the configuration of the parts being tested.

**Radiographic Stress Measurement without a Standard Material.** A. Thum, K. H. Saul and C. Petersen. (Zeitschrift für Metallkunde, 1939, vol. 31, Dec., pp. 352-358). A description is given of a new back-reflection technique of radiography which is particularly suitable for the measurement of elastic stress. The distance

from the camera to the specimen, which is a necessary unit in the calculation of the stress, instead of being determined by the simultaneous photographing of the interference lines of a standard material, is, in this new process, obtained from an "artificial line" produced by the scattered rays. It is shown that the cylindrical camera has certain advantages over the plane camera. The equations and calculations for evaluating the radiographs are explained. Some examples of the application of the new technique are discussed and it is shown that stress determinations in steel specimens can be made with an accuracy of  $\pm 0.5$  kg. per sq. mm.

**The Effect of Vanadium on the Grain Disintegration of Austenitic Chromium-Nickel Steels.** G. Riedrich and G. Hoch. (Stahl und Eisen, 1940, vol. 60, Jan. 11, pp. 30-31). The authors studied the effect of the presence of vanadium on the susceptibility to grain disintegration of steels containing 0.09% to 0.12% of carbon, about 18% of chromium and 9% to 14% of nickel. The results showed that, when forming carbide, vanadium in quantities up to twenty-five times the carbon content has no influence on the grain disintegration. When forming ferrite, however, vanadium renders the 18/8 chromium-nickel steels less susceptible to grain disintegration.

**Isothermal Transformation in Steels.** E. S. Davenport. (Transactions of the American Society for Metals, 1939, vol. 27, Dec., pp. 837-881). The author reviews the development and significance of the study of isothermal transformation as applied to the heat treatment of steel and outlines the important effects produced by alloying elements as revealed by studies of the isothermal transformation diagrams (the S-curves). He discusses the effects of the individual elements carbon, manganese, nickel, chromium, molybdenum, vanadium and cobalt, and presents the S-curves for several S.A.E. alloy steels containing 0.40% of carbon. With the exception of cobalt, all the alloying elements investigated retard the transformation of austenite in the Ar' range, provided that the element is in real solid solution in the austenite prior to transformation. Chromium, molybdenum and vanadium are most effective in this respect, with manganese next, whilst nickel and carbon exert a smaller but appreciable influence. Many of the 0.40% carbon alloy steels investigated have isothermal transformation curves which scarcely resemble the letter "S" and from the standpoint of both theory and practice the curves for these alloy steels have implications quite different from those of the now familiar S-curve for eutectoid carbon steel. The author concludes by discussing the hardness and microstructure of the S.A.E. steels transformed at several different temperature stages down to 600° F., and, where possible, correlates these with the corresponding trends as observed in carbon steels. Abridged versions of this paper have been published in Iron Age, 1939, vol. 144, Nov. 2, pp. 48-53, and Metal Progress, 1939, vol. 36, Nov., pp. 623-629.

**Kinetics of the Partial Transformation of Austenite.** H. Jolivet and A. Portevin. (*Génie Civil*, 1939, vol. 115, Dec. 30, pp. 464-465). The rate of isothermal transformation of austenite in a carbon steel near to the eutectoid composition is independent of the temperature at which it was held before quenching, and when transformed at successive temperatures the transformation curve is made up of portions of the curves characteristic of each temperature, except for a short initial period. This is no longer true for low alloy steels in which separation of ferrite brings about a marked change in the concentration of the residual austenite.

**The Influence of Rate of Cooling on the Transformations in Vanadium Steels.** (*Metallurgist*, 1939, vol. 12, Dec., pp. 87-88). This is an abridged English translation of a paper by Wever and Rose which appeared in *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1938, vol. 20, No. 16, pp. 213-227. (*See Journ. I. and S.I.*, 1939, No. I., p. 64 A).

**The Aluminium Corner of the Ternary System Aluminium-Iron-Manganese.** E. Degischer. (*Aluminium-Archiv*, 1939, vol. 18, pp. 1-19). In order to study the aluminium corner of the aluminium-iron-manganese system the author produced melts containing up to 25% of iron and up to 23% of manganese and studied their structures in the cast, slowly cooled and homogenised states, by applying microscopic, thermal and X-ray examinations. He confirmed the great solubility of iron in  $Al_6Mn$ . At room temperature no intermediate ternary phase occurs in the aluminium corner. There is a ternary eutecticum at  $654.1^\circ C$ . containing 1.8% of iron and 0.7% of manganese. The author determined the temperature of the binary aluminium-iron eutectic as  $654.3^\circ C$ .

**The Iron-Cobalt-Antimony System.** W. Geller. (*Archiv für das Eisenhüttenwesen*, 1939, vol. 13, Dec., pp. 263-266). The author discusses the binary iron-cobalt and iron-antimony systems, and studies the iron-cobalt-antimony system by thermal, dilatometric and microstructural investigations. The compound  $CoSb$  and the  $\epsilon$ -phase of the iron-antimony system form a continuous series of solid solutions which divide the ternary iron-cobalt-antimony diagram into two parts. The compounds  $CoSb_2$  and  $FeSb_2$  also form a continuous series of solid solutions.

**Ternary Alloys of Iron, Manganese and Chromium.** R. S. Dean, C. T. Anderson, C. Moss and P. M. Ambrose. (*United States Bureau of Mines*, Nov., 1939, Report of Investigations No. 3477, pp. 43-47). Previous investigators, particularly Burgess and Forgeng, have shown that the iron-manganese-chromium system has an austenitic range extending at  $700^\circ C$ . up to about 10% of chromium and from about 20% to 45% of manganese at this chromium content. Outside this area three other phases have been identified, namely, the ferrite, manganese and the so-called "sigma" phases. The present authors report briefly on the results of their investigations of the relationship between these phases. In con-



structing their iron-manganese-chromium diagram they show that the austenitic area is not extended greatly by the use of pure iron and electrolytic manganese, or by quenching from 1200° C. A ductile alloy is obtained, however, over a considerably extended area by quenching from 1200° C. This area of ductile alloys extends particularly along the pseudobinary lines connecting the composition  $\text{Fe}_2\text{Mn}_3$  with the compositions  $\text{FeCr}$  and  $\text{Mn}_3\text{Cr}$ . This area may be divided into three zones, depending on the behaviour on reheating to 700° C. after quenching from 1200° C. These three zones are: Area *A* with up to 25% of manganese, which loses magnetism but does not harden; Area *B* with from 25% to 45% of manganese, which loses magnetism and hardens; and Area *C* with from 45% to 64% of manganese, which is non-magnetic in all states, but hardens on reheating.

**The Oxygen/Hydrogen/Molten-Iron System.** H. Lepp. (Iron and Steel Institute, 1940, *see* this Journal, Section I.). In this study the author attempts to demonstrate the co-existence in molten iron of the oxide ( $\text{FeO}$ ) and of absorbed hydrogen (hydride), his calculations being based on experimental data already published. The process of interaction of water-vapour with molten iron seems to be capable of being represented very well by the reaction:



and the equilibrium constant of this reaction by the equation:

$$\log K = + \frac{23,586.3}{T} - 7.5526.$$

## ANALYSIS

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(Continued from pp. 109 A-111 A)

**A New Instrument for the Magnetic Determination of Carbon in a Steel Bath.** H. K. Work and H. T. Clark. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1132: Metals Technology, 1939, vol. 6, Dec.: Iron Age, 1939, vol. 144, Nov. 2, pp. 53-56). The authors describe the principles of an electrical instrument for the rapid determination of carbon in steel and its development for use in a steelworks, and discuss the accuracy of the results obtained with it. The instrument, called the "carbanalyzer," is a special form of permeameter, for it measures the change in flux in a bar produced by a known change in magnetising force; readings are taken from a galvanometer, the scale being calibrated in terms of carbon content. It is claimed that the instrument is relatively inexpensive, requires little upkeep, and can be used by the melter. It can be set up in any reasonably clean position in the open-hearth shop. The accuracy of the determination on a single sample is good, and the average of three or more determinations taken in rapid succession is very accurate indeed.

**The Rapid Determination of Carbon and Silicon in Cast Iron.** F. Roll. (Giesserei, 1940, vol. 27, Jan. 12, pp. 9-11). The author reviews the chemical and spectrographical methods for the determination of carbon and silicon in iron and points out that none of these methods can be carried out sufficiently rapidly in a foundry to make the results available before casting. As a means of determining the solidification characteristics of iron he favours the casting and breaking of a small wedge-shaped sample. He describes a special form of wedge used by himself and K. Sipp with which the silicon and iron contents could be determined in  $2\frac{1}{2}$  min. when these lie within the ranges carbon 3.14%-3.46% and silicon 1.12%-2.09%. The method is, therefore, very suitable as a means of controlling the cupola melting process.

**Contribution to the Quantitative Polarographic Determination of the Alloy Constituents in Special Steels.** M. von Stackelberg, P. Klinger, W. Koch and E. Krath. (Archiv für das Eisenhüttenwesen, 1939, vol. 13, Dec., pp. 249-262). The authors discuss the degree of accuracy which can be achieved in polarographic analyses and the suitability of this technique for the analysis of steel. They describe a new form of cathode which they developed. This provided data from which calibration curves could be drawn. Comparative solutions can be dispensed with by the application of these curves. They describe the technique to employ for making polarographic determinations of manganese, nickel, cobalt, chromium,

molybdenum, tungsten and vanadium when present in steel. In conclusion they discuss the future possibilities of this process of testing steel.

**Titration with Polarometric Indication of the End-Point.** A. Neuberger. (*Archiv für das Eisenhüttenwesen*, 1939, vol. 13, Oct., pp. 171-174). The author reviews the history of the development of polarometric titration and considers how the method might be applied with advantage to analyses in the steelworks laboratory. He deals in particular with the electrical parts of the apparatus used.

**Manganese and Chromium in Steel.** R. P. Forsyth and W. F. Barfoot. (*Industrial and Engineering Chemistry, Analytical Edition*, 1939, vol. 11, Nov., p. 625). The authors have modified the persulphate-arsenite method used for the determination of manganese in steel. They reduce permanganic acid in the presence of osmium tetroxide which is effective as a catalyst. The method allows the simultaneous determination of chromium and manganese. The experimental procedure is described in detail.

**The Determination of Ferrous and Ferric Oxide in Sponge Iron.** N. I. Stogniy. (*Zavodskaya Laboratoriya*, 1939, No. 4-5, pp. 391-395). (In Russian). The application of the Wilner-Merck method of dissolving iron in mercuric chloride was tested in its application to sponge iron. After dissolution of the iron, the residue of ferrous and ferric oxides is filtered off through a Gooch crucible and dried at 150° C. in a constant stream of dry nitrogen. Before determining the ferrous oxide in the residue it is necessary to remove the traces of mercury which would interfere with this determination. The mercury is evaporated off in a stream of chlorine at 200-220° C. (The apparatus for drying the ferrous and ferric oxide residues and then evaporating the mercury is described). The residue, free from mercury, is dissolved in hydrochloric acid in an Erlenmeyer flask fitted with a Bunsen valve and an inlet tube for carbon dioxide; the ferrous iron in the solution obtained is then determined by titration with potassium permanganate the usual way.

**Spectrograph Design and Its Problems.** J. W. Forest. (*Industrial and Engineering Chemistry, Analytical Edition*, 1939, vol. 11, Oct. 15, pp. 568-571). The author briefly reviews the developments in the design of spectrographs during the last sixty years.

## BOOK NOTICES

(Continued from pp. 168 A-171 A)

AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS.  
 "Transactions. Vol. 135. Iron and Steel Division, 1939."  
 8vo. Pp. 590. Illustrated. New York, 1939: The  
 Institute. (Price \$5.00.)

The 1939 volume of the Iron and Steel Division includes, among other important metallurgical papers, Dr. H. W. Gillett's interesting Howe Memorial Lecture entitled "Some Things We Don't Know about the Creep of Metals." This, together with Professor D. Hanson's Lecture, which is published in the current Institute of Metals Division volume (vol. 133), summarises the status of current knowledge on this important subject. Abstracts of all the papers contained in this volume are to be found in Section II. of the *Journal of the Iron and Steel Institute*. A complete list of the papers is as follows: Some Things We Don't Know about the Creep of Metals, by H. W. Gillett; Reduction of Iron Ores under Pressure by Hydrogen, by M. Tenenbaum and T. L. Joseph; Induction Furnaces for Rotating Liquid Crucibles, by E. P. Barrett, W. F. Holbrook and C. E. Wood; Mechanism of Solidification and Segregation in a Low-Carbon Rimming-Steel Ingot, by A. Hayes and J. Chipman; Solidification of Rimming-Steel Ingots, by A. Hultgren and G. Phragmén; Dendritic Structure of Some Alloy Steels, by D. J. Martin and J. L. Martin; Occlusion and Evolution of Hydrogen by Pure Iron, by G. A. Moore and D. P. Smith; Structure of Iron after Compression, by C. S. Barrett; Structure of Iron after Drawing, Swaging and Elongating in Tension, by C. S. Barrett and L. H. Levenson; Magnetic Torque Studies of the Texture of Cold-rolled and of Recrystallised Iron-Silicon Alloys, by L. P. Tarasov; Influence of Atmosphere and Pressure on Structure of Iron-Carbon-Silicon Alloys, by A. Boyles; Kinetics of the Decomposition of Austenite at Constant Temperature, by J. B. Austin and R. L. Rickett; Reaction Kinetics in Processes of Nucleation and Growth, by W. A. Johnson and R. F. Mehl; Phase Changes in 3.5 per cent Nickel Steel in the  $Ac_1$  Region, by I. N. Zavarine; Chromium in Structural Steel, by W. Crafts; Surface Allotropic Transformation in Stainless Steel Induced by Polishing, by J. T. Burwell and J. Wulff; Nature of Passivity in Stainless Steels and Other Alloys, I and II, by H. H. Uhlig and J. Wulff; Thermal Expansion of Nickel-Iron Alloys (Nickel from 30 to 70 per cent), by J. M. Lohr and C. H. Hopkins; Low-Temperature Transformation in Iron-Nickel-Cobalt Alloys, by L. L. Wyman; Fracture of Steels at Elevated Temperatures after Prolonged Loading, by R. H. Thielemann and E. R. Parker.

WHITE, A. H. "*Engineering Materials*." 8vo. Pp. x + 547.  
 Illustrated. New York, 1939: McGraw-Hill Book Co., Inc.;  
 London: McGraw-Hill Publishing Co., Ltd. (Price 30s.)

Although this book is not confined to metals, 312 out of the total of 534 pages of text are devoted to them, and the remainder of the volume deals with non-metallic materials under the chapter headings: Rocks and their Decomposition Products, Fused Silicates, Fuels,



Water, Organic Preservative Materials and Protective Coatings, and Plastics. The wider scope of the book distinguishes it from a number of other books addressed to engineers and concerned with metals only, but in so far as it deals with metals, the present work may be said to come into competition with several other books that are currently available. There are some people with so large a surplus of time or enthusiasm that they are prepared to read about the same subjects in book after book for the sake of the small additional amount of information they may pick up or the slightly different point of view they acquire. Few engineers adopt this attitude to books about metals, and in general they are inclined to get all their knowledge about this subject from one book at most. For their guidance someone ought to make a careful study of all the books dealing with metals from the engineer's standpoint and decide which is best, but only a few would learn of the verdict, and of these only a small proportion would accept it. This is probably as it should be, for it is doubtful whether anyone is competent to decide what metallurgical knowledge is essential to an engineer and how it should be presented to him. Books of the kind under consideration may be roughly classified into two groups, containing those written by metallurgists and engineers, respectively, and both types are liable to be unsatisfactory from one point of view or the other. The author of the present work is, however, a chemical engineer, and it is to be expected that he would have a better understanding of metallurgy than most other kinds of engineer, and a better appreciation of the engineer's requirements than most metallurgists. This is borne out by the book he has produced, for both in the selection of material and in its presentation he has achieved a very satisfactory result. In a book of this kind selection and presentation are the only features of the work for which the author has to accept responsibility, as most of the information he needs is readily available in numerous specialised works, and he does not require to deal with the more obscure and fundamental aspects of metallurgy about which there are differences of opinion and which can only be discussed with confidence after a careful study. It would be easy to criticise details of the work, for the author maintains the existence of  $\beta$ -iron and the amorphous grain boundary cement, uses the term ferrite as meaning iron, and therefore speaks of  $\gamma$ -ferrite, says that grain refinement will take place more rapidly  $200^{\circ}$  F. above the critical range than  $100^{\circ}$  F. above, and complicates his description of the changes in steel during normal heating and cooling by assuming that carbon in solution in iron must change to  $\text{Fe}_3\text{C}$  before it can crystallise as cementite and that  $\alpha$ -iron is formed in  $\gamma$ -iron and then deposited from solution. But whatever may be true in other branches of science and technology, it would be difficult to find a metallurgical book that could not be criticised when studied in detail. In view of this, reviewers should confine their remarks to general features, and from this point of view the present work can be described as a very satisfactory outline of metallurgy as related to engineering. It is well written, the illustrations are plentiful, well chosen and well reproduced. Most of the information used has been selected from the best available sources, and the ground covered is appropriate to the purpose of the book. The first chapter is introductory and deals rather too briefly with crystals and crystallisation, equilibrium diagrams, mechanical properties and testing. After that, the iron-carbon diagram is described, and this is followed by chapters on heat treatment, the manufacture of iron and steel, the properties of carbon and alloy steels, casting and cast iron, the metals copper, nickel, zinc, tin, aluminium, magnesium, lead and their alloys, and the corrosion and protection of metals.

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## MINERAL RESOURCES

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(Continued from p. 63 A)

**Magnetic Survey of Haematite Ore in South Cumberland and Furness.** A. F. Hallimond and J. T. Whetton. Bulletin of the Geological Survey of Great Britain, 1939, No. 2, pp. 1-17). The authors present an account with numerous diagrams of a magnetic survey of a hematite ore body near Millom in Cumberland, which is known to have a cross-section of about 50 ft., a depth of 100 ft. and a cover of about 60 ft. of boulder clay. This work has fully confirmed the original observation that the Cumberland hematite is appreciably magnetic.

**The Chromite Deposits in the Ratnagiri District and Savantvadi State, Bombay Presidency.** L. A. N. Iyer. (Records of the Geological Survey of India, 1939, vol. 74, Part 3, pp. 372-385). The author reports on his survey of the occurrence of chromite and other minerals in two deposits in the Bombay Presidency. Both deposits are accessible to the ports of Malvan and Devgad, and the reserves in the two localities are estimated at about 67,000 tons. The chromic oxide content of the ore varies between 30% and 39%.

**The Mineral Resources of the Central Provinces and Berar.** M. S. Krishnan. (Records of the Geological Survey of India, 1939, vol. 74, Part 3, pp. 386-424). The author surveys the geological occurrence of the mineral deposits of the Central Provinces of India.

**The East-German Iron-Ore Deposits and Their Exploitation in Connection with the Four-Year Plan.** E. Weg. (Stahl und Eisen, 1940, vol. 60, Jan. 11, pp. 21-29).

**Iron Ore Resources of Eastern Germany.** (Iron and Coal Trades Review, 1940, vol. 140, Feb. 23, pp. 321-322). An abridged English translation of Weg's paper is presented. (See preceding abstract).

**The Development of the Industry of Upper Silesia in Relation to History and Economic Space.** G. Behaghel. (Stahl und Eisen, 1940, vol. 60, Feb. 1, pp. 89-100). The history of the development and the position in November 1939 of the coal, iron, lead and zinc industries of Upper Silesia are presented.

**Iron Ore on the Mediterranean Seaboard.** J. H. Goodchild. (Mining Magazine, 1939, vol. 61, Dec., pp. 333-343). The author discusses the origin and geochemical significance of the iron-ore beds of the Sierra Nevada and the coastal plain of Vera in south-east Spain.

## REFRACTORY MATERIALS

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(Continued from p. 172 A)

**Alumina and Silica Refractories.** H. M. Kraner. (Iron Age, 1940, vol. 145, Jan. 18, pp. 25-30 ; Jan. 25, pp. 34-39). The author reproduces the diagram of the alumina-silica system by Brown and Grief and studies the properties of refractories made from American flint and plastic fireclays as well as those of semi-silica bricks (silica 70-85%). In the second part of his paper he describes some of the manufacturing processes and methods of testing refractory bricks.

**Present Application and Possible Future Development of Blast-Furnace Refractories.** W. R. McLain. (Bulletin of the American Ceramic Society, 1940, vol. 19, Feb., pp. 62-68). The author discusses the wear of various parts of a blast-furnace lining in relation to the quality of the refractory bricks used. From observations made in American blast-furnace practice it appears that molten iron is lost through the hearth and a "bear" begins to form after the furnace has produced about 300,000 tons of pig-iron. The author presents some analyses of both new and used blocks from the hearth, and of bricks used in blast-furnace stoves. In conclusion, he suggests that the increased cost of using selected refractories for the parts of the furnace subject to most wear would be more than repaid by the decreased frequency of repairs and the increased efficiency in operation.

**Refractories Used in the Steel Foundry.** A. V. Leun. (Transactions of the American Foundrymen's Association, 1940, vol. 47, Mar., pp. 534-541). The author describes the refractory bricks and clays used for lining open-hearth and electric steel furnaces, regenerator chambers, ladles and annealing furnaces in accordance with American practice.

## FUEL

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(Continued from pp. 173 A-176 A)

**Heat Transfer and Loss of Pressure when Gases Pass Across Nests of Tubes.** E. Hofmann. (*Zeitschrift des Vereines deutscher Ingenieure*, 1940, vol. 84, Feb. 10, pp. 97-101). The author discusses formulæ for calculating the heat-transfer coefficient for gases passing across nests of tubes, and various modifications which have been developed, as a result of tests in Germany and other countries, and which permit more accurate predictions of heat and pressure losses to be made.

**The Mixing Process in Gas Burners of Various Designs.** H. Schwiedessen. (*Archiv für das Eisenhüttenwesen*, 1940, vol. 13, Jan., pp. 283-292). The author discusses the conclusions reached during an investigation of the combustion of gases issuing from burners of several different types. The investigation was carried out at the Wärmestelle, Düsseldorf. The burners studied fell into four distinct groups, *viz.* : (1) Those producing axial-tangential flow ; (2) those producing parallel flow ; (3) those producing turbulent flow ; and (4) those which obtained the air supply by suction. The authors are of the opinion that many burners now produced are too complicated and that a standardisation of design is necessary.

**Control of a Coal Washing Plant.** (*Colliery Guardian*, 1940, vol. 160, Feb. 9, pp. 218-219). An illustrated description is given of the General Electric Co.'s system of control of a large number of motors driving a coal-washing plant at one of the pits of Glass Houghton and Castleford Collieries, Ltd. In this system the motors are distributed over a large area and the control system is centralised.

**Centrifuges for the Removal of Moisture from Coal Fines.** Ya. I. Fomin. (*Koks i Khimiya*, 1939, No. 6, pp. 3-7). (In Russian). A survey is made of the operating characteristics and efficiencies of both horizontal and vertical centrifuges including the Simplex, Hamborn, Carpenter and Wendell types. While the Carpenter centrifuge is regarded as preferable owing to its simple construction, efficiency, low wear of screens and low running speeds, it is nevertheless concluded that none of the types is capable of reducing the moisture content of washed coal below 4-6%, which is the maximum permissible in order to prevent the freezing together of the Donetz coking coals.

**The Coke-Oven Plant Heated by Lean Producer Gas at the Cokeries de la Seine.** C. Berthelot. (*Génie Civil*, 1940, vol. 116, Feb. 24, pp. 129-132). The author presents an illustrated description of the gas-producing plant and equipment which provide gas for heating the three batteries of Becker coke-ovens at the Cokeries de la Seine

near Paris. There are eight producers of the Marischka type with revolving grates each consuming 20–22 tons of coke breeze in 24 hr.

**Laboratory Coking Tests.** J. Roberts. (Coke and Smokeless-Fuel Age, 1940, vol. 2, Jan., pp. 10–12). The author briefly reviews a number of methods of making laboratory tests with coking coal and criticises Seyler's objections to the new British Standard and other tests. In conclusion he describes a simple furnace of his own design which consists of two blocks of insulating material (either moler or dextramite), each  $4\frac{1}{2}$  in. deep, with central holes 5 in. in dia. These, when placed one on top of the other, will accommodate a crucible  $4\frac{1}{2}$  in. in dia. up to 9 in. deep. Charges ranging from 100 to 500 g. can be used and a test can be completed in 60–75 min. The crucible is heated with a ring burner consuming only 25–30 cu. ft. per hr. This apparatus has been used with success for prescribing blends to be used in coke-ovens and retorts.

**Laboratory Apparatus for the Low-Temperature Carbonisation of Coal by the Hot-Surface Process.** K. Scheeben. (Technische Mitteilungen Krupp, Forschungsberichte, 1940, vol. 3, Jan., pp. 39–44). The author describes a laboratory apparatus for making low-temperature carbonisation tests, which, by reason of its size and capabilities of adjustment, is very suitable for studying the properties and composition of the coke and by-products produced. The results obtained with it can be used to predict with accuracy the behaviour of the same coal in a full-scale plant. It is specially suitable for ascertaining how coal will behave in the Krupp-Lurgi carbonising process. The procedure and evaluation of results are described in detail with some examples. The carbonisation temperature maintained during the tests is about 600° C. and the coking time is 5 hr. The author reproduces curves showing the changes in temperature, rate of gas evolution, composition of the gases and the tar production at different temperatures.

**The Temperature Schedule in the Coking of Coal.** D. S. Dorofeev. (Koks i Khimiya, 1939, No. 6, pp. 21–25). (In Russian). In laboratory tests on five different kinds of coal, the effect of the rate of heating up of the samples on the properties of the finished coke was studied by placing 600-g. samples of the coal in iron containers and placing them in a furnace held at a different temperature for each test. It is concluded that in order to conserve the coking properties of the coal, heating up to complete fusion should be as rapid as possible. From that point to 600° C. a definite rate of heating is required depending on the kind of coal. This rate determines the density, size, tendency to crack and mechanical strength of the coke. Above 600–650° C., the rate of heating has little effect on the quality of the coke and the rate should be as high as possible.

**Method of Calculating the Flame Temperature in Coke-Ovens Heated with Blast-Furnace Gas.** E. V. Virozub. (Koks i Khimiya, 1939, No. 6, pp. 18–21). (In Russian). A mathematical discussion. The formula derived is used in a specimen calculation and for evaluat-



ing the factors affecting the output capacity of the coke-ovens. The factors studied were the preheating of the air and gas, and the ratio of the air-gas mixture.

**Production of Pitch Coke.** S. Gorelik. (Koks i Khimiya, 1939, No. 4-5, pp. 42-43). (In Russian). Some details are given of the operations and experience at the Staro-Makoevskiy plant. The pitch used for making coke has a softening temperature of 65-75° C., 65-75% of volatile matter, 25% of free carbon and a specific gravity of 1.265-1.285. The yield from the coking furnaces operated at 950-1000° C. consists of coke 65%, tar 25% and gas 10%. The coke obtained contains 0.51% of sulphur, 4.72% of moisture, 0.63% of volatile matter and 0.24% of ash. The fireclay linings of the retorts were attacked by the molten pitch and have recently been replaced by linings of denser semi-acid bricks.

**The Chemical Effect of Supersonics.** W. Demann and H. R. Asbach. (Technische Mitteilungen Krupp, Forschungsberichte, 1940, vol. 3, Jan., pp. 12-25). After explaining the principles of supersonics, how supersonic waves are produced, and reviewing some results obtained by the application of supersonics in various spheres of science, the authors present an account of a series of investigations begun by the firm of Krupp in 1936 with the object of determining the effects of supersonics on polymerisation and condensation. These two processes play an important part in the treatment of the aliphatic-naphthenic and of the aromatic hydrocarbons produced during the refining of coke-oven by-products. The results demonstrated that the application of supersonics to a chemical reaction either accelerated the reaction so as to produce a higher yield, or to produce the same yield in a shorter time, or it enabled the pressure and temperature of the reaction to be reduced, thus tending to inhibit undesirable secondary reactions. The authors therefore conclude that the influence of supersonics on chemical reactions can be described as that of a "physical catalyst."

**Extraction of Pitch.** W. Demann and H. Porsch. (Technische Mitteilungen Krupp, Forschungsberichte, 1940, vol. 3, Jan., pp. 26-33). The authors report on a series of pitch-extraction experiments undertaken with the object of determining whether extraction residues could be obtained which, when suitably prepared and mixed with coals with poor coking properties, would enable a good-quality coke to be produced.

**The Lustre, Tinge and Reflective Characteristics of Cokes.** L. M. Sapozhnikov and K. I. Syskov. (Koks i Khimiya, 1939, No. 4-5, pp. 3-7). (In Russian). An electrophotometer used for tests on specimens of coke formed in plastometer tests at a final temperature of 750° C. is described. Lustre is defined as the light intensity measured with the reflecting surface of the coke inclined at 45° to both the incident rays and to the axis of the photo-electric cell. The light intensity due solely to the tinge of the coke is measured with the reflecting surface inclined at 22.5° or 67.5° to the incident ray. The reflect-

ivity of the specimen is given by the difference between the lustre and tinge measurements. Measurements were made on surfaces formed by cracks through the specimens and also on artificial cleavage planes. Consistent results were obtained without the need for any preparation of the reflecting surfaces. The possibility of using the results of optical measurements for the classification of coals and cokes is envisaged.

**X-Ray Determination of the Cracks in Coke.** V. I. Danilov, M. A. Levastevich and I. Z. Oliferenko. (*Koks i Khimiya*, 1939, No. 4-5, pp. 50-51). (In Russian). The authors present some preliminary data obtained in experiments in which radiographs of coke specimens were used to measure both the length and extent (area) of the cracks. Better definition was obtained by impregnating the coke with solutions of heavy salts (such as copper sulphate) before examination. The X-ray method indicated that the number of cracks increased with the number of inclusions in the coke.

**Breeze-Burning Producers at the Manchester Corporation Gasworks.** A. L. Holton. (*Coke and Smokeless Fuel Age*, 1940, vol. 2, Jan., pp. 18-21). The author describes the constructional details, the operating procedure and the results obtained with the Trefois and the Power Gas Corporation producers at the Manchester Corporation gasworks. Both these producers consume coke breeze.

**Turbo-Blowers at Coke-Ovens and Gas Works.** C. Berthelot. (*Génie Civil*, 1940, vol. 116, Feb. 3, pp. 86-87). The author describes some of the turbo-blowers and pressure regulators used in the long-distance gas-supply system of the Société régionale de Distribution du Gaz in the north of the Pas-de-Calais region.

**Hydrogenation of Typical North American Splint Coals.** A. Eisner, G. C. Sprunk, L. Clarke, C. H. Fisher and H. H. Storch. (*Industrial and Engineering Chemistry, Industrial Edition*, 1940, vol. 32, Jan., pp. 73-77). The authors present the results of hydrogenation tests on several typical North American splint coals. The information obtained showed that these coals are similar to European splint coals in being less suitable for hydrogenation than bright coals.

## PRODUCTION OF IRON

(Continued from pp. 177 A–179 A)

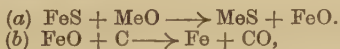
**Republic's Warren Furnace—The World's Largest.** G. F. Kerwin and T. J. Ess. (Iron and Steel Engineer, 1940, vol. 17, Jan., pp. 33–40). The authors present a complete technical description of the reconstructed and enlarged blast-furnace at the Warren Works, Ohio, of the Republic Steel Corporation.

**Republic's Blast-Furnace Largest in Effective Working Volume.** (Blast Furnace and Steel Plant, 1939, vol. 27, Dec., pp. 1219–1222). An illustrated description is given of the reconstructed and enlarged blast-furnace recently blown in at the works of the Republic Steel Corporation, Warren, Ohio. This furnace is now over 100 ft. high, with a hearth diameter of 27 ft., a volume of 44,562 cu. ft. and a productive capacity of 1200 tons of iron per day.

**Developments in the Iron and Steel Industry during 1939.** W. H. Burr. (Iron and Steel Engineer, 1940, vol. 17, Jan., pp. 52–69). The author surveys improvements to plant and processes which have taken place at American coke-ovens, blast-furnaces, steel furnaces and rolling mills during 1939.

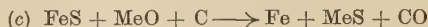
**The Influence of the Physical and Mechanical Properties of Coke on the Blast-Furnace Process.** S. K. Trekalo and G. A. Volovik. (Koks i Khimiya, 1939, No. 4–5, pp. 45–49). (In Russian). There was no relation between the output capacities of the two 950-cu. m. blast-furnaces at the Zaporozhstal works, where the observations were made, and the results of drum test on the cokes from Donbass coals. The crushability of the coke was found to have an influence upon the operation of the furnace, and this was expressed by a coefficient which takes into account the cracks in the coke developed during the various stages of transport of the coke from the ovens to the blast-furnaces. This coefficient could be obtained by a form of drop test in which the development of cracks larger than 2 cm. was taken into account.

**The Reactions of Iron Sulphide with Oxides, Carbonates, Silicates and Phosphates in the Presence of Carbon in the Heating of Powdered Mixtures.** W. Oelsen and H. Maetz. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1939, vol. 21, No. 23, pp. 335–351). The desulphurisation of iron in the blast-furnace is based on the two following reactions in which Me is a metal other than iron:



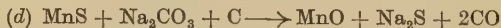
and they can take place at temperatures at which the components are still mostly in the solid state. As there is little information

available as to whether the reactions take place simultaneously at low furnace temperatures, or, if not, in what sequence and how far they approach towards completion, the authors undertook a number of experiments by heating mixtures of powdered iron sulphide and charcoal together with one of a number of oxides, carbonates and phosphates. Curves were obtained showing the loss in weight of the sulphide in relation to temperature in accordance with the reaction :



The authors arrived at the following conclusions concerning the reactions of these materials with iron sulphide in the presence of charcoal: (1) With the oxides CaO, SrO and BaO, exothermic reactions took place in accordance with equation (a) at temperatures generally below 900–1050° C., which are considerably lower than that of the rapid reduction by the charcoal of the ferrous oxide formed. The total reaction in accordance with equation (c) is therefore practically complete below 1050° C. The heating curves for the mixtures indicating the commencement of both the exothermic and endothermic reactions in accordance with equations (a) and (b) also enable the course of the reactions to be followed. (2) Manganous oxide also reacts with the ferrous oxide and charcoal in the temperature range 900–1050° C. to form manganese sulphide, and, therefore, before it can be reduced to manganese, which would occur at 1320–1450° C. (3) Magnesium oxide requires a temperature of at least 1300° C. before it reacts with iron sulphide and charcoal in accordance with equation (c). (4) Chromium oxide reacts in accordance with equation (c) at about the same temperature as that at which it is reduced when heated with charcoal alone. (5) When silica, in the form of ground quartz, intimately mixed with iron sulphide and charcoal, was heated to 1460–1480° C., the reaction was so lively that the heating curve exhibited an arrest resembling a boiling point. In this reaction heavy, suffocating, silicon-sulphide fumes were evolved. (6) Alumina did not react until 1600° C. was reached. (7) The experiments with the carbonates CaCO<sub>3</sub>, SrCO<sub>3</sub>, BaCO<sub>3</sub>, Na<sub>2</sub>CO<sub>3</sub>, K<sub>2</sub>CO<sub>3</sub> and CaNa<sub>2</sub>(CO<sub>3</sub>)<sub>2</sub> showed that the loss of weight began at lower temperatures than in the case of the oxides, and at much lower temperatures than those at which they were reduced with charcoal alone.

In order to examine the behaviour of the manganese sulphide during the desulphurisation reactions, a series of experiments were made by converting the sulphide with soda and with lime in the presence of charcoal. The reaction with soda is very vigorous at the low temperature of 720–900° C. in accordance with the equation :



As soon as the manganous oxide is reduced to manganese, however, sodium vapour begins to form. The reaction of the sulphide with



lime and charcoal takes place and approaches completion at 1350–1500° C. In this case, too, the reduction of the manganous oxide with charcoal is a very vigorous reaction. A knowledge of the extent to which the reaction capacity of the lime and of the sodium oxide in the silicates, aluminates and phosphates is decreased is also very important. The lime in the silicates  $\text{CaO} \cdot \text{SiO}_2$  and  $2\text{CaO} \cdot \text{SiO}_2$  reacted with iron sulphide and charcoal only at much higher temperatures than did the pure solid lime. The raising of the reaction temperature of the lime-alumina compound  $5\text{CaO} \cdot 3\text{Al}_2\text{O}_3$  is lower than that of the lime-silica compounds; the lime in the solid aluminate is therefore not fixed to the same degree as it is in the silicates. In mixtures in which the lime is not combined with the silica, the lime reacts with the iron sulphide and charcoal before the formation of iron silicates. The reaction with the sodium metasilicate  $\text{Na}_2\text{O} \cdot \text{SiO}_2$ , iron sulphide and charcoal takes place at much higher temperatures and much more slowly than does the soda reaction. The lime in the tri-calcium phosphate  $\text{Ca}_3(\text{PO}_4)_2$  reacts vigorously with iron sulphide and charcoal at 1100–1250° C., but the phosphoric acid of the phosphates combines with the adjacent iron; the temperature of the reduction of this phosphoric acid is much lower in the presence of iron sulphide than in the presence of silica. The reaction of the sodium oxide from the phosphate  $\text{Na}_4\text{P}_2\text{O}_7$  with iron sulphide and charcoal proceeded practically to completion at 950–1100° C. with the simultaneous reduction of the phosphoric acid. On the other hand, the reaction of molten sodium pyrophosphate with a high-sulphur molten pig-iron took place very slowly, and the desulphurisation was not complete until most of the phosphoric acid had been reduced.

**Powder Metallurgy Has Great Design Potentialities.** G. Z. Griswold. (Machine Design, 1940, vol. 12, Jan., pp. 41–43, 83). The author points out some of the advantages of extending the application of powder metallurgy to the manufacture of metal parts and gives numerous examples of both ferrous and non-ferrous parts successfully manufactured by this process.

## FOUNDRY PRACTICE

(Continued from pp. 180 A-181 A)

**The Melting of Cast Iron.** K. Bunin and D. Katsnel'son. (Metallurg, 1939, No. 8, pp. 3-10). (In Russian). The mechanism and kinetics of the melting of the following irons were studied :

	C %.	Si %.	Mn %.	S %.	P %.
White . . . .	3.28	0.44	0.75	0.1	0.5
Grey . . . .	2.85	1.73	0.87	0.09	0.4

A mottled cast iron of the same composition as the white was also used. Specimens in the form of cubes of 4.5 mm. side were rapidly introduced into a magnesite crucible heated to one of the test temperatures (1160°, 1210°, 1260° C.), held for a certain time and then quenched in water. After quenching, the graphite content, hardness and microstructure were investigated. It is concluded from the results that the melting process is primarily based on diffusion phenomena, and that the mechanism can be satisfactorily explained by a scheme based on the generally accepted iron-carbon equilibrium diagram. The rate of solution of graphite at temperatures approaching the eutectic temperature is very slight and, as a result, the rate of melting at these temperatures is appreciably influenced by the original structure. At high temperatures the original structure has no noticeable effect on the rate of melting. Cast irons melted at temperatures above the eutectic, while appearing to be white from their fracture and microstructure, nevertheless contained small amounts of graphite which could be determined by chemical analysis. The amount of this graphite was independent of the original structure, but varied with the composition of the iron. There is no reason for supposing that this graphite represents graphite undissolved during melting.

**The Electric Furnace in the Grey Iron Foundry.** T. Klingenstein and H. Kopp. (Giesserei, 1940, vol. 27, Feb. 9, pp. 41-47). An abridged version is presented of the authors' paper on experience gained from electric-furnace practice in the grey-iron foundry of Maschinenfabrik Esslingen. (See p. 77 A).

**Cuts Costs on Cast Steel Gears.** J. A. Shuffstall. (Foundry, 1940, vol. 68, Jan., pp. 28-30, 92). The author describes suitable moulding technique for the preparation of moulds for casting large steel gears.

**Synthetic Moulding Sand.** A. Tipper. (Institute of British Foundrymen: Foundry Trade Journal, 1940, vol. 62, Feb. 8, pp. 119-122). The author describes the preparation and properties of

synthetic moulding sand. The advantages and disadvantages of this sand may be summarised as follows : *Advantages*—(1) Lower cost of sand maintenance and no necessity for dumping large quantities of used sand ; (2) improvement in permeability and lower moisture content decreases the number of blown or porous castings ; (3) the sand is easy to mould with lower moisture content and gives higher production ; (4) it enables semi-skilled labour to be used on machines with satisfactory results ; and (5) it is possible to use old core sand or reclaimed floor sand for some classes of work. *Disadvantages*—(1) High first cost is probable ; (2) the sand loses moisture more or less rapidly, which may cause friable edges on moulds ; (3) patching, unless extra care is taken, may ruin the mould, since strength is quickly lost with excess water ; (4) balling up of the sand may be experienced due to a variety of causes ; and (5) strict control is necessary.

**Reminiscences of a Foundryman.** (Iron and Steel, 1940, vol. 13, Jan., pp. 105–108). For the benefit of apprentices and younger foundrymen who have had no experience of preparing loam moulds, the author, who adopts the pseudonym of Tubal Cain, describes the tools used and the procedure for making a loam mould for a cast iron wheel with the aid of striking boards or sweeps. The sweep is a board, pivoted at one end, the edge of which is profiled to reproduce the shape of the desired casting.

**New Foundry Builds Truck Engines.** P. Dwyer. (Foundry, 1940, vol. 68, Jan., pp. 23–27, 84–86). The author describes and illustrates the plant and lay-out at the new foundry of the International Harvester Co., at Indianapolis. This foundry will be devoted to the production of grey-iron castings for motor-lorry engines and to their machining and assembly. A high degree of mechanisation has been achieved and an initial production rate of 700 engine units per day, with a gradual expansion up to 2000, is contemplated.

**The Flowability of Cast Steel.** E. C. Kron and C. H. Lorig. (Transactions of the American Foundrymen's Association, 1940, vol. 47, Mar., pp. 583–605). After reviewing the literature on castability tests for molten cast iron and steel with special reference to the Ruff test, the authors describe a modified form of Ruff test developed by themselves, the mould for which was such that about 100 lb. of steel was poured before the test channels were filled. This technique permitted the lip of the ladle and the various channels in the mould to be heated up before the actual test was made. They reproduce numerous temperature/length-of-flow curves from data obtained in the laboratory and from 27-ton open-hearth heats using steel of various analyses. These curves show that moderate increases in the carbon, silicon, manganese or copper increase the castability, whilst titanium in high-manganese, high-silicon, copper-bearing steel decreased its castability. In conclusion they stress the importance of obtaining accurate readings of the temperature

of the steel, as they themselves found that readings taken by sighting an optical pyrometer on the surface of the steel were far from satisfactory. The method they adopted was to immerse a clay-graphite tube with a closed end to a depth of about 5 in. and to take readings with an optical pyrometer mounted in line with it.

**Malleable Iron Castability Tests.** E. J. Ash. (Transactions of the American Foundrymen's Association, 1940, vol. 47, Mar., pp. 609-615). The author describes some castability tests on cast iron for malleablising using a modified form of the Saeger-Krynitsky spiral mould in which the effects of certain ladle additions were demonstrated. The results obtained showed that: (1) The addition of ferro-silicon as a deoxidiser improved the castability; (2) the addition of iron oxide as an oxidiser decreased the castability; and (3) the addition of a deoxidiser to the oxidised metal improved the castability as compared with (2), but the results were not so good as those obtained with the metal in the "as melted" state. In general, the tests indicated that maximum castability is associated with a certain critical oxygen content in the bath, probably in the form of iron oxide, and at higher or lower concentrations the castability is reduced.



## PRODUCTION OF STEEL

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(Continued from pp. 182 A–185 A)

**The Open-Hearth Furnace and Its Auxiliaries.** G. D. Tranter. (Metal Progress, 1940, vol. 37, Jan., pp. 34–38). The author presents an account of improvements in basic open-hearth furnace design and practice which have taken place in America during the last ten years.

**Uses and Metallurgy of Ferrous Scrap Metals.** M. W. von Bernewitz. (Blast Furnace and Steel Plant, 1939, vol. 27, Dec., pp. 1226–1230). The author reviews the uses of ferrous scrap metals and discusses the melting procedure when scrap is charged in various proportions in blast-furnaces, cupolas, Bessemer converters, open-hearth furnaces and electric furnaces.

**The Absorption and Evolution of Hydrogen during the Process of Steel Making.** S. von Hofsten, Bo Kalling, F. Johansson and O. Knös. (Jernkontorets Annaler, 1939, vol. 123, No. 10, pp. 485–526). (In Swedish). The authors report on an investigation, sponsored by Jernkontoret, which had as its object the study of the influence of the hydrogen content of molten steel upon the refining process. The methods of collecting and analysing the hydrogen were the same as those used in an earlier investigation by Kalling and Rudberg (*see* Journ. I. and S.I., 1938, No. II., p. 139 A). The conclusions reached were as follows: (1) When the composition of the gases evolved from the steel is known, the hydrogen content of the steel bath can be calculated using Sievert's tables for the solubility of hydrogen in steel. Direct determinations of the hydrogen content in steel by the vacuum-fusion process have been made for comparison purposes, but the degree of agreement was only fair. Testing the evolved gases is probably more reliable, and it also enables a good estimation of the changes in the hydrogen content to be made as the refining process proceeds. (2) It has been found that the amount of hydrogen given off from steel boiling in an atmosphere free of hydrogen bears a distinct relationship to the process of carbon removal, and this can be plotted as a curve, called the standard curve. The nature of the curve has been determined from a study of a number of charges in a high-frequency furnace in which special measures were taken to produce a high hydrogen content when the tests commenced. The increased solubility of hydrogen at high temperatures causes a displacement of the standard curve. (3) Theoretical calculations based on Sievert's results and on the assumption that the evolved gases are in equilibrium, produce a marked deviation from the shape of the normal curve, and thus give rise to doubt as to the correctness of Sievert's solubility tables. (4) If the furnace gases also contain hydrogen or hydrogen compounds, then, while

hydrogen is being evolved from the boiling steel, some absorption of the hydrogen from the furnace gases will also take place, but the hydrogen content will not be entirely eliminated, as a continuous state of equilibrium will be reached at which the evolution and the absorption are taking place at the same rate. (5) The amount of carbon which it is necessary to remove in the refining process for the state of equilibrium referred to above to be reached appears never to exceed 0.3%, even when the hydrogen content of the steel is high. (6) The principal factors governing the amount of hydrogen absorbed from the furnace gases are the hydrogen content of the gases and the protective action of the slag. High temperatures seem to favour hydrogen absorption, especially with basic charges. (7) When hydrogen is introduced into the charge—for example, by rusty or oily scrap—it is driven off at an early stage; in fact, most of it is evolved before the charge melts. If the melting is followed by refining down to 0.2–0.3% of carbon, the hydrogen content of the charge will have no bearing upon the hydrogen content of the steel. (8) A considerable quantity of hydrogen can be added to the steel in other ways, *e.g.*, from burnt lime which has been partially slaked, or from moist ore. If too much hydrogen is added by means of these additions, the hydrogen content will become dangerously high unless the refining is continued for a sufficient length of time after the additions were made. (9) There are certain indications that the absorption of hydrogen can be affected to an important extent during the process of tapping, as, for example, by damp launders, or if there is too much tar on the inside of the ingot moulds. These factors can affect the hydrogen content of the finished steel even more than the reactions in the furnace itself.

The following points are of interest with regard to the behaviour of hydrogen in the different steelmaking processes: (a) As a rule the hydrogen content is lower in steel from an electric furnace than from an open-hearth furnace because, in the former case, the furnace gases contain less hydrogen; (b) in high-frequency furnaces some analyses of the evolved gases have shown no hydrogen at all, although the state of equilibrium referred to in conclusion (4) is normally 1–3% in an open-hearth furnace; (c) the slag in an acid open-hearth furnace appears to absorb more hydrogen than that in a basic open-hearth furnace. When the charge is ready for tapping, the hydrogen content of the evolved gas is usually about 1% with acid charges as compared with 2–3% with basic charges; (d) burning the iron increases the rate of hydrogen absorption, but if the surface of the melt has become completely covered with slag, the hydrogen content rapidly reverts to normal; (e) in the Bessemer processes the hydrogen content should be maintained at a level corresponding with the moisture content of the blast, which is about 0.6% at 0° C. and 3–1% at 25° C.

**The Formation of Slag in the Open-Hearth Process.** W. Bischof. (Archiv für das Eisenhüttenwesen, 1940, vol. 13, Feb., pp. 325–332).

The author studied the properties of the slag produced during the open-hearth process by means of samples taken from three different melts in a 25-ton basic furnace. The charges for the three melts produced slags of a sufficiently wide range to be representative of the whole field of open-hearth practice. He reproduces several photographs of the surface of solidified slags, and micrographs of slag sections, and relates these to the lime/silica ratio and the viscosity. He establishes by the evaluation of results obtained from samples taken before tapping that the limits of the reaction capacity of the slag are related to the temperature of the steel and composition of the slag.

**Top Charge Rapid Type Furnaces in the Manufacture of Plain Carbon Steels.** H. H. Watson. (Canadian Metals and Metallurgical Industries, 1939, vol. 2, Dec., pp. 308-310). The author describes and illustrates a 5-ton direct-arc electric steel furnace with a removable roof which enables "top-charging" to be completed in about 5 min. He describes the whole melting procedure and compares the costs of ingots made in door-charging and top-charging electric furnaces of this size.

**Advancements in Melting Technique Using Coreless Induction Furnaces.** O. Dörrenberg and W. Bottenberg. (Stahl und Eisen, 1940, vol. 60, Feb. 8, pp. 116-119). The authors describe the development in Germany during the last ten years of the coreless induction furnaces for steel-making. There are now 140 of these furnaces producing steel in that country.

**Refining Slags in High-Frequency Steel-making.** N. F. Dufty. (British Steelmaker, 1940, vol. 6, Feb., pp. 36-37). The author describes some aspects of slag manipulation in the refining of steel in coreless induction furnaces.

**Measurements of the Viscosity of Acid Open-Hearth Slags.** A. D. Kramarov. (Metallurg, 1939, No. 8, pp. 38-40). (In Russian). In the absence of any data on the viscosity of acid open-hearth slags, the Herty slag viscosimeter was used to measure the viscosity of a number of slags taken at different periods of the melting process. When plotted, the viscosities exhibited a straight-line relation to the silica content of the slag. In view of the probable difference in temperature, slags taken during the first and second periods of the heat have to be considered separately. It is possible to determine the silicon content from the viscosity with an error not exceeding 1.0-1.5%.

**The Solidification of a Steel Ingot.** V. M. Tageev and B. B. Gulyaev. (Metallurg, 1939, No. 8, pp. 23-38). (In Russian). Temperature measurements taken during the solidification of a 500-kg. ingot and additional measurements made in both the interior of a 7000-kg. ingot and on the walls of the mould are given in the present article. These are used in a mathematical discussion of the solidification process and to draw up a heat balance for the ingot. The 7000-kg. ingots were of chromium-nickel-molybdenum steel

and were top-poured into an octagonal mould (780 mm. across the bottom, 820 mm. across the top, 1260 mm. high and 200 mm. mean wall thickness). The general conclusion is that the temperature of the molten steel in the mould rapidly becomes uniform and equal to the liquidus temperature. The solidification time of the 7000-kg. ingots was 180 min. The more rapid rate of solidification of the central portion of an ingot observed in practice in the later stages of cooling is explained by the increase of the ratio of the surface to the volume undergoing solidification. The chief factor determining the solidification quantitatively is the temperature of the ingot surface, which, under ordinary conditions, usually has a mean value of  $1000^{\circ}$  C. The superheating of the melt, and consequently the pouring temperature, have little effect on solidification, as the heat given out as a result of superheating amounts to only 4–6% of the total heat loss. The heat given out on solidification and the heat removed from the solidified part of the ingot during solidification amount to 46% and 48% in a 7000-kg. ingot and to 50.3% and 44.8% in the 500-kg. ingot, respectively. The heat taken up by the mould (70–85% of the total) constitutes the major item on the other side of the balance. There is a certain size of ingot above which the time required for it to solidify is longer than that taken by the mould to reach its maximum temperature. After reaching that stage the mould actually retards solidification, heat removal taking place only as a result of losses from the surface of the mould.



## FORGING, STAMPING AND DRAWING

(Continued from p. 187 A)

**Forged Working Rolls for Cold-Rolling Mills and Their Manufacture.** R. Scherer. (Heat Treating and Forging, 1939, vol. 25, Dec., pp. 598-603, 615-616 : Blast Furnace and Steel Plant, 1939, vol. 27, Nov., pp. 1143-1145 ; Dec., pp. 1238-1241). An English translation is presented of a paper by R. Scherer on the design, manufacture, heat treatment and grinding of forged steel rolls for cold-rolling mills which appeared in *Stahl und Eisen*, 1939, vol. 59, Oct. 5, pp. 1105-1111. (See p. 86 A).

**Drawing Tests for Sheet Metal.** H. W. Swift. (Institution of Automobile Engineers, Symposium on Deep-Drawing Research, Mar. 19, 1940, Advance Copy, pp. 1-73). Bending, stretching and drawing occur together in most types of press operation, but in varying degree. Bending appears to present little difficulty in practice, though it is subject to a proposed standard test. Stretching may occur without drawing in certain shallow pressing operations, but the drawing does not occur without stretching under any normal conditions, and when material fails during pressing it almost invariably fails in a region subject to stretching as distinct from drawing. The author points out that these facts have led to the conception that the most suitable material for drawing purposes is one which can be subjected to the most stretching without fracture. This has led to the use, as a criterion of drawing quality, of either the elongation, measured in a tensile test, or the depth of penetration, determined in a cupping test. The author gives a critical review of the various types of cupping tests used in practice and of the theoretical investigations on their applicability carried out by previous authors. He then gives an account of his own study of the suitability of the cylindrical-cup pressing as a drawing test. The apparatus used, fitted with an autographic sub-press, is described in detail and numerous diagrams obtained with it are reproduced and discussed. The main points investigated were : (1) The relationship between blank diameter, punch load and success in drawing ; (2) strains and stresses produced by cup formation, including consideration of the development of stretcher-strains, ear formation, the residual stresses and the influence of the geometrical form of the cup ; and (3) effects of the drawing conditions, *viz.*, blank holding, clearance between punch and die, speed of drawing, curvatures of punch and die, and lubrication. In conclusion the author compares the relative importance of cupping and drawing tests, pointing out that these two forms of test are distinct and cannot properly be substituted for one another. Each of the two tests simulates a certain type of commercial pressing operation. The author con-

cludes, therefore, that the cupping test can be regarded as representative of flanged pressings and the drawing test as representative of pressings drawn through without a flange. Thus, each of the two forms of test has its range of application in connection with commercial press operation, and the author suggests the introduction of a machine adaptable for cupping and drawing tests. He also discusses some constructional features which would be required for such a machine. The paper is followed by two appendices. In the first one particulars are given of the materials tested, *viz.*, mild steel and a number of non-ferrous metals and alloys. In the second appendix an analysis is attempted of the stresses and strains which occur in a circular sheet when drawn radially towards its centre before it is bent over into cylindrical form.

#### **The Quench Ageing, Strain Ageing and Cold Working of Steel.**

J. H. Andrew, J. W. Rodgers, H. A. Wainwright and J. N. Blackhurst. (Institution of Automobile Engineers, Symposium on Deep-Drawing Research, Mar. 19, 1940, Advance Copy, pp. 74-114). In the introduction to their paper the authors give a comprehensive review of previous investigations on the effect of quench ageing, strain ageing and cold working on the mechanical properties of steel. They then give an account of their study of the effect of the heat treatment, quenching and cold-rolling conditions on the drawing properties of 0.06%-carbon rimming steel. The tests indicated a falling-off in drawability as ageing proceeds. Further, they report on a series of tests determining the changes in hardness, due to ageing, of cylindrical cups produced by the deep drawing of dead mild steel sheet using a commercial press. The ageing changes were erratic, as was to be expected from the nature of the steel used. In addition, a comparison of the ageing curves showed very markedly the non-uniformity of pressing conditions on similar parts of the cup. Only the ageing curves of the flanges showed a surprisingly uniform ageing effect over the whole width, and they agreed tolerably well with those of the rolled steel. The last part of the paper represents an account of tests made with the deep-drawing press with the object of studying the factors affecting the pressing of dead mild steel strip. The press used is described in detail. It allowed the production of cups from  $4\frac{1}{2}$ -in.-dia. blanks in one operation, technically known as raising. The authors enumerate fifteen factors which may affect the pressing performance and which are dependent partly on the pressing operation and partly on the state of the material. The influence of a number of these factors has been studied by the authors, *viz.*, the blank-holder pressure, the depth of draw, the blank diameter, the speed of drawing, the lubrication, the degree of cold reduction, the conditions of ageing and heat treatment, and the micro-structure. The results obtained by varying these factors are discussed and reproduced in extensive tables.

**A Study of the Deep-Drawing Characteristics and Testing of Sheet Metals.** C. A. Edwards, R. Higgins and T. D. Rees. (Institution

of Automobile Engineers, Symposium on Deep-Drawing Research, Mar. 19, 1940, Advance Copy, pp. 118-142). The authors give an account of their investigation of the behaviour of sheet metals during their plastic deformation in deep-drawing operations. They used a special testing machine, which is fully described in this paper, which they called the "Erichsen No. 2 Press." This press is designed to produce a small dish in two distinct operations. In the first place, the blank is pressed into a dish having an internal diameter of 33 mm., and then, after changing the punch and die, this is pressed into the form of a dish having an internal diameter of 26 mm. Nearly all the experimental work described was confined to the first of these two operations. The effect was also studied of the clamping pressure, the die clearance and the thickness of the flange, *i.e.*, that part of the original disc which is in contact with the blank holder up to the time it is drawn round the radius of the die. The experiments were, for the most part, carried out with hot- and cold-rolled steel sheets which had been subjected to different heat treatments and which varied in composition and thickness. The results obtained, which are reproduced in numerous diagrams, seem to indicate that the "Erichsen No. 2 Press" is capable of detecting differences in the pressing qualities of sheet material which are not revealed by the cupping test.

**Deep-Drawing Tests on Alloy Steel Sheet and Strip.** A. Pomp and A. Krisch. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1940, vol. 22, No. 3, pp. 19-34). In the deep-drawing tests here described the authors used sheet and strip from 18/8 austenitic chromium-nickel steels, chromium-manganese steels, 18% and 6% chromium steels, a 0.04% carbon steel and four steels containing 0.70%, 1.64%, 3.38% and 4.22% of silicon, respectively. The results obtained by four different methods of testing are compared and shown in comprehensive tables and graphs. The authors did not find any clear relationship between the test results and works experience. A comparison of the results of tests made at 20°, 100° and 200° C. showed that : (1) The 18/8 chromium-nickel steels had the best drawing properties at 20° and 100° C.; (2) the best temperature for the chromium-manganese steels was 200° C.; (3) the chromium steels behaved better at 20° and 100° C. than at 200° C.; (4) the carbon steel was unaffected by the temperature; and (5) the expectation that the drawing and rolling properties of the silicon steels would be improved by a slight increase in temperature was confirmed.

## ROLLING-MILL PRACTICE

(Continued from pp. 188 A-189 A)

**The Permissible Loading of Rolling-Mill Bearings in Relation to Temperature, Length of Pass and Rolling Speed.** L. Weiss. (Metallwirtschaft, 1940, vol. 19, Feb. 9, pp. 97-101). In this discussion of rolling-mill lubrication the author considers the permissible loading for bronze and synthetic-resin bearings lubricated with grease, the effects of length of pass and rolling speed, the flow of heat in cold rolling, bearing design, the relation of the roll dimensions to those of the material to be rolled, temperature and the maintenance of a continuous film, and smooth acceleration and retardation effects.

**Progress of Lubrication in the Steel Mill.** C. C. Pecu. (Iron and Steel Engineer, 1940, vol. 17, Jan., pp. 45-50). The author describes some recent advancements in the design of lubrication systems for rolling-mill machinery, and presents a tabular specification showing the properties of lubricants for various applications in the steel mill.

**Determination of the Output Capacity of a Four-High Cold Rolling Mill.** S. S. Chepurkin. (Metallurg, 1939, No. 8, pp. 68-79). (In Russian). After a brief description of the pack-rolling practice for sheets on a non-reversing four-high cold mill, the author derives a formula for the output capacity of the mill in terms of the various variables involved and illustrates its use by application to an actual example. The effect of the different factors is analysed. A formula derived for the output of a four-high reversing mill indicates that by reason of the reversing facilities an increase in the output of 19-24% could be obtained. Finally, a nomogram for non-reversing mills is presented.

**A Thickness Measurer for Cold Strip Mills.** L. Dubois. (Metallwirtschaft, 1940, vol. 19, Jan. 12, pp. 28-29). The author describes the principles and design of an electric instrument which continuously indicates and records the thickness of cold-rolled strip as it passes from the finishing rolls to the coiling drum.

**New Reel for Strip.** W. W. McBane. (Steel, 1940, vol. 106, Jan. 15, pp. 50-52). The author describes and illustrates a new form of reel for coiling narrow and medium-width hot strip and skelp which is now in use at some American strip mills. The boss of the reel, instead of being solid, is made up of fifteen vanes projecting in ring formation from a side plate which is connected to reduction gearing driven by an electric motor. The leading edge of the strip passes between a roller and a guide plate which guide it between the revolving vanes; the end is automatically bent over one of the vanes which continue to revolve, thus winding up the strip.



## HEAT TREATMENT

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(Continued from pp. 190 A–196 A)

**Case Hardening. A Review of Current Processes and Equipment.** G. T. Williams. (Industrial Heating, 1939, vol. 6, Oct., pp. 880–894, 956–957). In this, the first article of a series, the author reviews the chemical methods of case hardening, *viz.*, the various processes of carburising and nitriding, with special reference to the suitabilities of these processes for different purposes.

**Witherite in Case Hardening.** J. M. Noy and L. G. Bliss. (Foote-Prints on Chemicals, Metals, Alloys and Ores, 1940, vol. 12, No. 2, pp. 15–25). The authors describe an investigation of the factors affecting the activating effect of witherite (a natural barium carbonate) on the degree of carbon migration in the case-hardening process. Their conclusions were as follows: (1) Diminution of the particle size of barium carbonate increases its activity as an energiser; (2) the activity of each grade of barium carbonate is specific for a given particle size; (3) an increased barium-carbonate content in a case-hardening compound improves activity, but not in proportion with the increased barium-carbonate content; (4) natural barium carbonate probably contains inherently a trace of some element or elements that enhance its activity; and (5) super-airfloated natural barium carbonate was the most active energiser of those tested.

**Flame Hardening of Meehanite.** F. H. Bickford. (Iron Age, 1940, vol. 145, Jan. 11, pp. 19–21; Jan. 18, pp. 40–44). The author describes the equipment and procedure for the flame-hardening of Meehanite, a special cast iron with a minimum tensile strength of 22 tons per sq. in. and a modulus of elasticity of 21,000,000 used for making gearing, machine-tool and pressure castings. A particular application of the process is that by which the surface of rolls can be hardened. For this purpose a vertical boring machine can be converted fairly easily. With this machine the roll is mounted vertically and a double ring is supported horizontally from the tool holders so as to encompass the roll; the upper ring carries the oxy-acetylene burner tips, and the lower ring the quenching nozzles. The ring is moved slowly from the bottom to the top of the roll, which is revolved, and thus ensures that the surface is evenly heated. Some micrographs and a curve showing the different degrees of hardness at various depths of case of a bar of flame-hardened Meehanite are also presented.

**Flame Hardening—Its Applications in Important Industries.** H. S. Card. (Industrial Heating, 1939, vol. 6, Dec., pp. 1142–1146). Continuation of a series of articles (*see* p. 190 A). The author describes and illustrates many industrial applications of the process

of flame-hardening. The examples given include the hardening of gear teeth, straightening rolls and wobblers in rolling mills, the ways of lathe-beds, the rims of mechanical shovels and the jaws of crushing machinery.

**Refractory Radiant Tube Furnace Used for Pack Annealing of Silicon Steel Sheets.** D. P. Armbruster. (Industrial Heating, 1939, vol. 6, Dec., pp. 1159–1160). In the manufacture of silicon steel sheets for armature and transformer laminations a special heat-treatment technique is required involving a very slow heating-up, a long period of soaking and a final temperature of about 2000° F. In this paper the author describes a furnace, suitable for this treatment, heated by radiant tubes in which low-pressure natural gas is burnt. The interesting feature of this furnace is that the radiant tubes are not made of alloy steel, but of a refractory material the thermal conductivity of which is about ten times that of fireclay. The heating chamber of this furnace is 15 ft. 6 in. long  $\times$  11 ft. wide  $\times$  5 ft. 6 in. high.

**Practical Annealing.** E. G. de Coriolis. (Iron Age, 1940, vol. 145, Jan. 18, pp. 40–44; Jan. 25, pp. 30–33). After defining the terms full-annealing, normalising, process annealing, patenting, and spheroidising, the author discusses the effects of these processes on the properties of steel sheet and describes how some of the protective atmospheres used in annealing furnaces are prepared. He also discusses the furnaces used, the instruments for controlling the gas mixtures and furnace temperatures and the characteristics of open flame, radiation and convection furnaces.

**The Heat Treatment of Wire and Wire Products—Continuous and Batch Type Bright Annealing Plant.** (Wire Industry, 1940, vol. 7, Jan., pp. 19–23). Continuation of a series of articles (*see* p. 147 A). An illustrated description is given of the continuous roller-hearth type and the four vertical Grunewald type annealing furnaces at the wire works of Arthur Lee and Sons, Ltd. (*see* p. 22 A).

**Modern Electric Heat-Treatment Furnaces.** F. W. Haywood. (Midland Metallurgical Societies: Iron and Coal Trades Review, 1940, vol. 140, Jan. 26, pp. 197–198; Feb. 2, pp. 223–224; Foundry Trade Journal, 1940, vol. 62, Feb. 8, p. 124; Feb. 15, pp. 135–136). The author discusses the development of electric furnaces for the heat treatment of metals and deals with various designs, indicating their suitability for various classes of work.

**The Status of Prepared Atmospheres in the Heat Treatment of Steel.** B. W. Gonser. (Industrial Heating, 1939, vol. 6, Dec., pp. 1123–1134). A reproduction of a paper read before the American Gas Association in March 1939 (*see* Journ. I. and S.I., 1939, No. II., p. 271 A).

**Bright Annealing of Chromium-Bearing Steels.** O. Dahl and F. Pawlek. (Stahl und Eisen, 1940, vol. 60, Feb. 15, pp. 137–142). The authors discuss the properties essential to a protective atmosphere for the successful bright annealing of 18/8 stainless steels.

They construct equilibrium-temperature curves for the reactions between chromium and (a) a mixture of hydrogen and steam, and (b) a mixture of carbon monoxide and carbon dioxide. From these they show that protective atmospheres containing carbon monoxide, as obtained by the partial combustion of town-gas or propane, are unsuitable for bright annealing these steels. They also determine the maximum permissible moisture content in the protective atmospheres hydrogen, cracked ammonia, and cracked and partially burnt ammonia. Except in cases where a large hydrogen-producing plant is available, a protective atmosphere prepared from cracked ammonia is the most suitable for bright annealing the 18/8 stainless steels when purity, storage capacity and price are taken into account. In conclusion, the authors discuss the effect which the nitrogen absorbed by the steel has on its properties. These effects are: (1) The tensile strength is increased by about 30%; (2) the elongation is reduced by about 20%; (3) the resistance to corrosion remains unaltered; and (4) the susceptibility to intercrystalline corrosion is slightly decreased.

**Hardening Tappets.** (Steel, 1940, vol. 106, Jan. 22, pp. 54-56). A brief description is given of an electric-induction method of hardening inserts for the valve tappets of automobile engines. The inserts are placed in holes in the face of an intermittently revolving drum which carries them round between two inductor blocks. Heating to 1500° F. is practically instantaneous, and with further movement of the drum, the inserts pass through a spray of water and finally drop off on to a conveyer belt at the bottom of the machine. As many as 6000 parts per hr. can be hardened in this manner.

**The Cooling Capacities of Quenching Media for Steels.** A. Rose. (Archiv für das Eisenhüttenwesen, 1940, vol. 13, Feb., pp. 345-354). An abridged version of a paper which appeared previously in *Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1939, vol. 21, No. 11, pp. 181-196, is presented. (See Journ. I. and S.I., 1939, No. II., p. 272 A).

## WELDING AND CUTTING

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(Continued from pp. 197 A-201 A)

**Automatic Atomic Hydrogen Welding of Steel.** J. T. Catlett. (Iron and Steel Engineer, 1940, vol. 17, Jan., pp. 25-31). The author discusses the difficulties which have been overcome in designing machines for the automatic welding of steel by the atomic hydrogen process, describes the technique employed and gives particulars of costs based on American experience.

**Reducing Mill Machinery Wear.** (Blast Furnace and Steel Plant, 1939, vol. 27, Dec., pp. 1242-1245). Several applications of the process of facing the wearing surfaces of various items of rolling-mill equipment with a hard alloy by welding are described. These include the following: (1) Depositing a cobalt-chromium-tungsten alloy on the grippers of ingot cranes; (2) facing the guide-plates of a cogging mill; (3) facing hot, flying shear blades; and (4) facing the clutch-plates used in the drive of large shears.

**The Weldability of Heat Resisting Steels.** (Welding Industry, 1940, vol. 8, Feb., pp. 15-19). Reference is made to the heat-resisting properties and applications of six types of "Era H.R." steel which resist scaling at temperatures up to 1150° C. The welding rods, current strengths and welding technique for the electric and autogenous welding of these special steels are described in detail.

**The Bend Test on Weld Metal and Its Suitability for the Testing of Structural Steels.** E. Houdremont, K. Schönrock and H. J. Wiester. (Stahl und Eisen, 1939, vol. 59, Nov. 16, pp. 1241-1248; Nov. 23, pp. 1268-1273; Technische Mitteilungen Krupp, Forschungsberichte, 1939, vol. 2, Oct., pp. 191-205). After reviewing the reasons for the introduction of a special form of bend test as a means of determining the welding properties of structural steel, the authors discuss at length the factors affecting the values obtained by it with special reference to testing German high-tensile steel St 52. In this test a bead of weld metal is deposited on a steel slab 700 × 200 × 50 mm., which is then subjected to a bend test with the weld metal in tension, and the formation and growth of cracks in relation to the applied stress are observed. The authors also examine the relation between these bend-test results and the impact strength of similar specimens.

**The Examination and Tests of Welded Parts for Steam Power Plant.** A. H. Goodger. (Proceedings of the Institution of Mechanical Engineers, 1940, vol. 142, Jan., pp. 261-287). The object of the paper is to give the results of certain experimental and routine inspection work rather than to lay down rules of inspection and



testing. An outline is given of the margin obtained between some of the properties and requirements of actual boiler drums and the specified limits. European practice appears to favour acetylene welding for the butt-welding of tubes. Normally acetylene welds do not suffer from cracking at the base, but they do suffer from lack of penetration; some methods by which this can be overcome are given and some forms of joints for tubular welds are suggested. The inspection of tubular welds presents many problems, but certain non-destructive tests have been successfully applied, and a number of X-ray examinations on site are described. A useful method of inspecting large numbers of tubular welds by sample consists in carrying out a reverse-bend test on a tongue sawn out of the tube and pressed round a former. The paper also contains the results of extensive experience of the heat treatment of welds on site.

**Contribution to the Metallography of Welded Steel, Cast Iron and Malleable Iron.** F. Roll. (Metallwirtschaft, 1940, vol. 19, Jan. 12, pp. 19-21). The author discusses the influence of the cooling rate on the structure and hardness of welds in steel, cast iron and malleable iron.

**Cost of Cutting with Butane, Propane and Acetylene.** W. T. Tiffin and O. R. Eads. (Society of Automotive Engineers, Nov. 1939: Iron Age, 1939, vol. 144, Dec. 21, pp. 42-43). The authors report on the results of a series of cutting tests on steel plate with a cutting machine using butane, propane and acetylene as cutting fuels. Acetylene proved to be the cheapest fuel on the basis of cost per foot of cut, but propane gave the smoothest and cleanest cut, and the latter permitted fabrication by welding without having to clean the edges or to remove slag.

## CLEANING AND PICKLING OF METALS

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(Continued from p. 153 A)

**Some Aspects of Pickling.** (Wire Industry, 1939, vol. 6, Dec., pp. 757-761). The importance of careful pickling with subsequent thorough washing is pointed out, particularly with regard to the wire industry. The chemical processes in connection with hydrochloric and sulphuric acid pickling are briefly described.

**Electrolytic Polishing of Stainless Steel.** G. Kiefer. (Iron Age, 1939, vol. 144, Dec. 21, pp. 30-32, 66). The author describes in detail the electrolytic polishing of stainless steel as carried out by the Allegheny Ludlum Steel Corporation. The electrolyte used is a concentrated solution of ortho-phosphoric acid.

**Pickle Polished Stainless Steel.** T. W. Lippert. (Iron Age, 1940, vol. 145, Jan. 11, pp. 22-26). After referring briefly to several patents covering electrolytic processes for polishing stainless steel articles, the author describes a continuous plant used for polishing shelves for refrigerators. The solution is contained in a lead-lined tank 33 ft.  $\times$  5 ft.  $\times$  3 ft. The work is made the anode and a current density of 0.5-1.5 amp. per sq. in. is used. The shelves, which consist of spot-welded wire grids, pass through the tank in 6-10 min. and the discoloration produced by the heat of the welding is also removed. The plant has a capacity of 5000 shelves per day.

**Wastes Problems of the Iron and Steel Industries.** W. W. Hodge. (Industrial and Engineering Chemistry, Industrial Edition, 1939, vol. 31, Nov., pp. 1364-1380). The author reviews the extended researches which have resulted in the development of methods of preventing flue dust and also phenolic liquors from entering streams, and for utilising a large portion of these materials as well as slags. The main part of the paper, however, deals with the treatment of waste pickle liquor under the following headings: Disposal of waste pickle liquors with and without pretreatment, and without recovery of by-products; treatment of waste pickle liquor involving the recovery of usable by-products; recovery of copperas or siderotilate; recovery of copperas and free sulphuric acid; recovery of ferrous sulphate monohydrate and free sulphuric acid; ferric sulphate and sulphuric acid from waste pickle liquor; sulphuric acid and iron oxide from waste pickle liquor; electrolytic processes for recovering iron and regenerating the sulphuric acid; manufacture of iron oxide pigment and/or polishing rouge; Ferron from waste pickle liquor; manufacture of ammonium sulphate and iron oxide, sulphide or carbonate; other inorganic compounds from waste pickle liquor; uses and marketing of by-products. The paper contains 139 references to the literature and numerous illustrations.

## COATING OF METALS

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(Continued from pp. 154 A-157 A)

**The Determination of Metallic Brightness.** R. Springer. (*Zeitschrift für Elektrochemie*, 1940, vol. 46, Jan., pp. 3-13). The author describes a method of determining the brightness of metals by measuring with a Pulfrich photometer, the light diffusely reflected at an angle of 45°. Owing to its simplicity the method is suitable for industrial purposes and it can be used for the standardisation of metal surfaces, for the control of bright electroplating, for the determination of the amount of polish required and the effect of pickling and for the study of tarnishing.

**The Effect of Organic Compounds on Galvanic Nickel-Plating.** E. Raub and M. Wittum. (*Zeitschrift für Elektrochemie und angewandte physikalische Chemie*, 1940, vol. 46, Feb., pp. 71-82). The authors report on their investigation of the manner in which over a hundred different organic compounds promote the formation of a mirror-like surface in the process of nickel-plating.

**Phosphatising.** (*Automobile Engineer*, 1939, vol. 67, Dec., pp. 459-460). A comparison is made of the corrosion resistance of enamelled mild steel sheets which, before enamelling, were subjected to one of the three following treatments: (a) Solvent degreasing, phosphatising and rinsing in weak chromic acid; (b) solvent degreasing and phosphatising; and (c) solvent degreasing only. The results show the very beneficial effect of the chromic acid rinse. The various stages of the pretreatment are described and discussed.

**The Production of Copper- and Tombac-Coated Deep-Drawing Plates and Their Finishing.** C. Rademacher. (*Stahl und Eisen*, 1939, vol. 59, Dec. 28, pp. 1379-1382). The author presents a detailed account of the process of manufacturing steel plates coated on both sides with copper or tombac (tombac is an alloy of copper with a very small percentage of zinc). This is a process which has been used in Germany to produce a material for making hollow cylindrical articles which were formerly made of solid copper or brass. The steel plate, after careful pickling and cleaning, is placed between sheets of copper or tombac and the pack is clamped together by channels of cold-rolled steel strip 1 mm. thick. Adhesion of the coatings to the steel is obtained by heating the pack in an electric furnace to 950° C. for copper, or to 850-875° C. for tombac, with subsequent rolling under suitable pressure. The rolled plates, after etching (to reveal faults), washing, drying and brushing, are then stamped into round discs which are annealed and polished in a revolving drum containing sawdust.

**New Type of Stainless Steel Clad Carbon-Molybdenum Plate Developed.** (*Alloy Metals Review*, 1939, vol. 2, Dec., pp. 92-94).

Some particulars are given of the properties of "Croloy" bonded plate which is made by a process of continuous resistance welding. In this process a thin sheet of chromium steel (chromium 11-14%) is welded to a carbon-molybdenum steel plate with a thin layer of nickel in between. The process was described in more detail in Steel, 1939, vol. 105, Oct. 2, pp. 42-43, 63-64. (See p. 33 A).

**Galvanizing Steel Sash.** W. G. Imhoff. (Steel, 1940, vol. 106, Jan. 8, pp. 47-48). A brief description is given of the galvanising process used in the manufacture of galvanised steel window-frames.

**British Standard Specification for the Testing of the Zinc Coating on Galvanised Wires.** (British Standards Institution, No. 443-1939). This is a revision of the 1932 edition of Specification 443, and its principal feature is the introduction of a test for the minimum weights of zinc per unit area on zinc-coated wires.

**Developments in Electro-Tinplating of Strip Steel.** D. C. Bake-well. (Iron and Steel Engineer, 1939, vol. 16, Dec., pp. 37-38). After a review of the development of the electrolytic process of tin-plating steel strip, in which the use of a rotary brushing machine for the production of bright surfaces is discussed at some length, the author considers the working conditions essential for satisfactory results. He points out the advantages of the use of an acid bath and a soluble anode, and describes this technique in detail. Finally, the economic advantages of the electrolytic method are pointed out. The principal advantage is that, for equivalent results, less tin is required than in the hot-dip process.

**The Electrolytic Manufacture of Tinplate Strip.** C. C. Downie. (Sheet Metal Industries, 1940, vol. 14, Jan., pp. 29-30). The author reviews some modern methods for the electrodeposition of tin, and discusses the preliminary operations necessary, the current consumption, the electrolyte composition and the tests used for examining the tinplate strip produced.

**Metal Spraying Process in Maintenance Work.** J. G. Magrath. (Iron and Steel Engineer, 1939, vol. 16, Dec., pp. 22-25). The author enumerates parts of plant and machinery which can be repaired by metal spraying, and discusses the choice of the metal to be applied for various kinds of repair work.

**Electromagnetic Method of Determining the Thickness of Enamel Coatings.** K. Azarov and N. Kharchenkova. (Zavodskaya Laboratoriya, 1939, No. 4-5, pp. 508-512). (In Russian). The simple instrument for determining the thickness of enamel coatings described involves the measurement of the change in the magnetic resistance of a closed magnetic circuit consisting of the electro-magnet and the iron object carrying the enamel or other non-ferromagnetic coating. Alternating current is used. Test results, while in general satisfactory, are affected by temperature, owing to the use of a cuprous oxide rectifier in the circuit.

**Effects of Humidity and Composition on Strength and Young's Modulus of Enamels.** D. G. Moore and W. N. Harrison. (Journal



of Research of the National Bureau of Standards, 1939, vol. 23, Sept., pp. 329-342). The authors determined Young's modulus and the modulus of rupture of eight types of enamel frit under constant conditions of temperature and humidity and studied the effect of changes in humidity on these moduli.

**Effect of Enamel on the Strength of Enamelling Iron.** A. I. Andrews and E. W. Dietterle. (Journal of the American Ceramic Society, 1940, vol. 23, Jan., pp. 29-32). The authors give an account of some bend tests the results of which showed that enamel applied to one or both sides of iron and steel sheet greatly increased the strength of the specimen, particularly if the original sheet was of light gauge. An increase in the thickness of the enamel increased the strength within limits. Too heavy an application of enamel, however, caused failures within a small range of deflection because the enamel chipped or cracked away from the specimen. This indicates that there is a maximum thickness at which the enamel will give added strength to the metal sheet.

**Better Adherence.** H. E. van Sichen. (Steel, 1939, vol. 105, Nov. 20, pp. 66-69). The author considers the factors which affect the adherence of paint coatings to galvanised iron and presents a number of charts, based on practical adherence tests, which enable the effects of different cleaning processes on the adherence of paint to be compared.

## PROPERTIES AND TESTS

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(Continued from pp. 203 A-209 A)

**Test-Piece for Investigating the Yield Point in Iron and Steel.** A. M. Baxter and Constance F. Elam. (Engineering, 1940, vol. 149, Feb. 16, p. 176). The authors point out some disadvantages of the usual design of test-piece for tensile tests, in particular that of the effect of the localisation of stress due to change in cross-sectional area. They then describe a special design of specimen intended to obviate these disadvantages. The specimens to the new design are 10 in. long with a centre portion 0.5 in. in dia.  $\times$  6 in. long, and at each end a 1.5 in. length is turned down to 0.35 in. in dia. On loading such a test-piece, the two small-diameter ends will extend a certain amount before the stress is sufficient to cause yielding in the centre portion. If, after the ends have yielded, the test-piece is turned down until the diameter is the same throughout, a test length is obtained in which the ends being hardened by cold work, perform the same function as enlarged ends in an ordinary test piece, without the disadvantage of change of shape. The results of some tests with specimens of this type are presented and discussed.

**The Yield of Mild Steel with Particular Reference to the Effect of Size of Specimen.** J. L. M. Morrison. (Proceedings of the Institution of Mechanical Engineers, 1940, vol. 142, Jan., pp. 193-222). In this paper a description is given of an investigation undertaken to determine by tests, under various conditions of uniform and non-uniform stress distribution, the criterion of yield in specimens of mild steel. Apparatus is described for heat treating the material after machining in such a manner as to avoid surface decarburisation, and for determining the stresses at yield of specimens tested in tension, compression, flexure, torsion, and combined tension and torsion. The tests in combined tension and torsion give results which accord with the theory of yield at a critical value of the shear-strain energy stored per unit volume of the material, this result being shown to be due to the size of the specimen tested. In cases of non-uniform stress distribution, the yielding proves also to depend on the specimen size. In such cases, yield is delayed until a shear stress not less than the shear stress at yield under uniform stress, is applied to a thickness of material of the order of a few crystal diameters.

**The Effect of Cracks on the Calculated Nominal Stress of a Specimen Subjected to a Constant Bending Moment.** R. Moufang and R. Mailänder. (Materials Committee of the Lilienthal Gesellschaft, June, 1939: Technische Mitteilungen Krupp, Forschungsberichte, 1939, Anhang, pp. 15-17). A mathematical treatise.

**An Investigation into the Occurrence and Causes of Locomotive Tyre Failures.** C. W. Newberry. (Proceedings of the Institution of Mechanical Engineers, 1940, vol. 142, Jan., pp. 289-303). A detailed investigation has been made into the causes of locomotive tyre failures from two standpoints: first, to determine the cause of any particular failure, and second, to find general relationships between effect and cause in the matter of tyre defects. Examples are given of the examination of individual failures, and of experimental work directed to the improvement of wheel and tyre. In a statistical review, it is shown that fatigue is the major cause of tyre failure, and many of the factors which might influence the development of fatigue failure have been critically examined and their responsibility assessed. In conclusion it is noted how, by a change in tyre-boring methods so as to increase the effective fatigue strength of the tyre, and by modifications in design to ensure more uniform stress distribution in the tyre, the occurrence of fatigue failure has steadily declined.

**Some Notes on the Development of Fatigue Strength Investigations.** E. Houdremont. (Materials Committee of the Lilienthal Gesellschaft, June, 1939: Technische Mitteilungen Krupp, Forschungsberichte, 1939, Anhang, pp. 1-8). The author discusses various aspects of fatigue testing, in particular the relationship between the tensile strength, elastic limit, fatigue strength and time-resistance (*see* Journ. I. and S.I., 1938, No. II., p. 35 A) of steel specimens. He points out that the capacity of a material to withstand loads above the fatigue strength is of less interest to the designer than the limit of the permissible overload for a given number of stress reversals. So far, most investigations of fatigue have been concerned with certain specific objects and the general theory of fatigue has been neglected. As fundamental theories worthy of further examination the author suggests: (1) The first disruption occurring in a fatigue test may take place in the range of atomic dimensions; (2) the amount of heat produced at the position of the first disruption has an important influence on the subsequent fatigue behaviour of the specimen; (3) from the phenomenon stated in (2) it follows that the fatigue strength of different metals is also related to the melting point; and (4) some phenomena have been observed which lead to the conclusion that the damping capacity of a specimen increases as the fatigue test proceeds, and other observations point to the contrary being the case. In conclusion he points out the need for differentiating between fatigue tests with the object of obtaining data useful to the constructional designer, and those made with the object of studying the theory and nature of fatigue.

**Influencing the Life of Fatigue-Stressed Parts by Periods of Rest.** K. Daeves, E. Gerold and E. H. Schulz. (Stahl und Eisen, 1940, vol. 60, Feb. 1, pp. 100-103). The authors report on their investigation of the factors affecting the "limited fatigue range"

of steel, *i.e.*, the number of stress reversals at above the fatigue strength which a specimen will withstand before fracture. A number of specimens of patented and cold-drawn steel wire of different carbon contents were tested in a Schenck rotary bend-testing machine, the applied stress was increased at certain time intervals so as to exceed the fatigue strength of the specimen and the effects of different periods of rest at different temperatures were studied. Their conclusions were as follows: (1) When specimens which had been stressed above the fatigue strength were given periods of rest, the steel "recovered," and its life on subjection to further stressing was increased; (2) the sooner the specimen was rested after stressing above its fatigue strength, the greater was the increase of its life; (3) an increase in the rest period from one-half to three days also prolonged its life, but this effect was much less than that obtained as described in (2); (4) specimens previously subjected to various forms of heat treatment behaved differently; the greatest degree of recovery was shown by those with a coarse pearlite-ferrite structure and a decarburised surface; and (5) a greater degree of recovery was obtained by maintaining the specimen during the rest period at a temperature above 50° C. but below that at which any change in mechanical strength would take place. The authors point out that the results obtained prove that the laws governing the limited fatigue range of steel are different from those governing its behaviour when stressed below the fatigue strength.

**Results of Fatigue Tests on Steels.** R. Mailänder. (Materials Committee of the Lilienthal Gesellschaft, June, 1939: Technische Mitteilungen Krupp, Forschungsberichte, 1939, Anhang, pp. 8-15). The author describes some of the fatigue-test investigations which have been carried out in Krupp's laboratories. The tests described include the following: (1) Bend-fatigue tests of 45 mm.-dia. steel specimens; (2) torsion-fatigue tests of crankshafts with 45 mm.-dia. crankpins; (3) the relationship between fatigue strength and tensile strength; (4) fatigue strength of specimens with very sharp notches; (5) the effect of nitriding on the fatigue strength; and (6) short-time corrosion fatigue tests.

**Fatigue Problems in Structural Designs.** A. V. Karpov. (Metals and Alloys, 1939, vol. 10, Dec., pp. 381-388). Conclusion of an article (*see* p. 205 A). In the second part of this paper the author considers the transmission of stresses through welded and riveted joints and the fatigue strength diagrams used when designing these joints.

**The Wear-Resistance of Cast Iron Under Conditions of Reciprocating Motion.** E. M. Rosenberg. (Vestnik Metallopromyshlennosti, 1939, No. 7, pp. 32-38). (In Russian). In the first part of this article a recently developed wear-testing machine and the method of testing used are described, and in the second part some experimental data for the effect of such external factors as lubrica-



tion (clean and dirty lubricants), original surface finish, speed and pressure on the wear of cast iron are presented.

**Testing Gear-Wheel Material.** A. Meldahl. (Brown Boveri Review, 1939, vol. 26, Oct., pp. 235-240). A new apparatus developed by Brown Boveri and Co., Ltd., for the testing of gear-wheel blanks is described and illustrated and some results obtained with it are given. It is shown that the direction of the sliding movement plays a preponderant part in the durability of the material.

**Creep at High Temperatures.** H. J. Tapsell. (North-East Coast Institution of Engineers and Shipbuilders, Feb., 1940). In this paper descriptions are given of the creep characteristics of metals with special reference to the behaviour of carbon and molybdenum steels. The manner in which the tensile properties, such as ultimate stress and limit of proportionality, are influenced by creep is first described, and then follows an account of the general behaviour of metals during creep and of the influence of temperature, stress, and time. The latter half of the paper deals specifically with the creep properties of carbon and molybdenum steels. Considerable variations in the creep properties of carbon steels of similar carbon content have been encountered, and this important feature is well illustrated by the data provided, which also show that steels containing 0.13-0.4% of carbon have much the same properties around 450° C. Molybdenum steels of similar composition also vary considerably in creep properties, although they are much superior to carbon steels. The addition of a small percentage of vanadium to molybdenum steels produces further improvement. The effect of heat treatment is described, particular attention being given to the effect of prolonged heating during service. Methods of estimating working stresses are given, and numerical data and curves show how experimental results may be utilised.

**The Strength Properties of Alloy Steels at Low Temperatures.** A. Krisch and G. Haupt. (Archiv für das Eisenhüttenwesen, 1940, vol. 13, Jan., pp. 299-308). The authors report on an investigation of the impact strength, hardness and tensile strength of pure soft iron, fifty-nine low-alloy steels, nickel, electrolytic copper and lead at the temperature of liquid air, and in some cases, at that of liquid hydrogen. Their conclusions were as follows: (1) A number of nickel, chromium-nickel and chromium-manganese steels, especially those with austenitic structure, as well as nickel, copper and lead, all showed a high capacity for plastic deformation at temperatures down to -183° C.; (2) those steels containing nickel had the highest impact strength; (3) chromium-molybdenum steels with and without small nickel additions had impact strengths up to 5 m. kg. per sq. cm. at -183° C.; (4) tempered steel had a higher impact strength at low temperatures than untempered steel; (5) pure soft iron became exceedingly brittle at these low

temperatures; (6) the impact strength of copper and lead decreased with decreasing temperature; (7) the hardness increased with falling temperature in all cases; (8) the increase in hardness was less with those materials with high hardness values at room temperature; (9) the chemical composition affected the increase in hardness; (10) the tensile strength of the steel alloys increased as the temperature decreased, and the amount of the increase depended upon the tensile strength at room temperature; and (11) the reduction in area was in many cases only half as much as that at room temperature.

**Method of Sclero-Grating Employed for the Study of Grain Boundaries and of Nitrided Cases; Grain Structures Revealed by Cutting.** Bo O. W. L. Ljunggren. (Iron and Steel Institute, 1940, *see* this Journal, Section I.). Use has been made of the method of Benedicks and Mets for the detailed study of relative hardness, namely, ruling a fine grating on a polished metal surface. This procedure—designated here as “sclero-grating”—has been made highly sensitive, mainly by making the point-bearing part very light, with great lateral stability. Thus, the hardness difference between adjacent grains clearly reveals the grain structure of a metal—as in grain field etching. By the use of very low pressure and a small ruling distance it is possible to detect cold-working resulting from grinding. On iron as well as on aluminium, after annealing in nitrogen, grain boundaries were observed for which the sclero-grating method indicated a slightly greater hardness than that of the groundmass, without any separated phase being visible there under the microscope. This may be interpreted as a molecular enrichment of nitride in the boundaries in support of the theory of Benedicks and Löfquist. It has been shown that in order to reveal small hardness differences, a strictly geometrical shape of the ruling point is by no means necessary; particularly high sensitivity is frequently attained through the action of a “secondary point.” Good harmony has been found to exist between the configuration of the ruling point and the rulings obtained when examined at a high magnification. The sclero-grating method has been employed for the detailed study of the individual hardness of the micro-constituents of a nitrided case. Consideration of the results obtained seems to provide a reasonable explanation of the behaviour of the total-hardness curve of a nitrided steel. In connection with the sclero-grating experiments some tests have been made on the cutting of soft metals with a sharp knife (a laterally extended point). When using a sufficiently large free-cutting angle the grain structure was beautifully developed, and also a remarkable coarse structure which may be considered to be a characteristic feature of “pure” metals. During the work, a few other observations were made. Thus, on prolonged heating of commercial aluminium, the compound  $\text{Al}_3\text{Fe}$  was found to protrude above the free surface of the specimen; in a nitrided surface, a certain crack formation

was observed and is explained as being due to blisters caused by local high pressure.

**The Effect of Hydrogen in Steels of Various Compositions.** W. Eilender, Y. C. Chiu and F. Willems. (Archiv für das Eisenhüttenwesen, 1940, vol. 13, Jan., pp. 309-316). Continuing their investigation of the behaviour of hydrogen in steel (*see* Journ. I. and S.I., 1939, No. II., p. 114 A), the authors now report on the structure and hydrogen content of, and rate of hydrogen evolution from specimens of plain and alloy steels, melted under different conditions of de-oxidation, to which hydrogen had been purposely added. In unalloyed steels the evolution of gases proceeded more slowly with increasing carbon content. Increasing the content of the alloying element also slowed down the gas evolution except in the case of niobium which produced the opposite effect. Austenitic and ferritic steels did not give off any gas, whilst there was always some evolution from ferritic-pearlitic and martensitic steels, excepting those containing titanium. It was evident that the evolution of hydrogen from super-saturated steels is closely connected with the transformation phenomena. Under certain conditions it is possible to use niobium for expelling hydrogen, but most of the alloying elements absorb hydrogen, so that if they are added to the steel on completion of the refining process, they can function as hydrogen-absorbing media.

**The Effect of Small Additions of Molybdenum on the Properties of Chromium Structural Steel.** N. P. Ostroumov. (Metallurg, 1939, No. 8, pp. 41-50). (In Russian). With a view to the possibility of reducing the expensive molybdenum content in the widely used steel with 0.35% of carbon, 1.0% of chromium and 0.25-0.40% of molybdenum, four heats of similar steel with 0.38%, 0.17%, 0.10% and with no molybdenum were studied. The steels contained in addition 0.31-0.39% of silicon, 0.53-0.60% of manganese, 0.28-0.30% of nickel, 0.011-0.017% of sulphur and 0.024-0.033% of phosphorus. The 1-ton acid open-hearth ingots were rolled down to 25-mm.-dia. rod. The investigation included microstructural examination, dilatometric tests, determination of the grain size by the McQuaid-Ehn method and studies of the grain growth on heating (oxidation method), the effect of heat treatment on the mechanical properties and hardenability, and the effect of molybdenum on the sensitivity of the steel to the rate of cooling when tempering. The stability of the supercooled austenite and the hardenability of the steel were found to increase with increasing molybdenum content. Also, as the molybdenum content is increased, the grain-growth tendency at temperatures between 870° C. and 960° C. is reduced. Temper-brittleness is eliminated by the addition of 0.1% of molybdenum. As regards mechanical properties, and in particular, the impact strength, a marked increase is caused by the addition of 0.1-0.17% of molybdenum, a further increase having less effect. It is therefore concluded that the



addition of 0.1% to 0.17% of molybdenum is sufficient. Any further increase raises the cost of the steel and also increases the tendency to flake formation as well as necessitating special methods of casting and forging.

**Manganese Case-Hardening Steels, Low in Imported Alloying Elements, with Additions of Chromium, Silicon or Vanadium.** H. Schrader and F. Brühl. (Technische Mitteilungen Krupp, Forschungsberichte, 1939, vol. 2, Dec., pp. 207-215). The authors survey the results of investigations of the mechanical properties of chromium-molybdenum steels with a view to establishing to what extent they could be replaced by unalloyed steels with the carbon and manganese contents suitably adjusted for hardening purposes.

**Manganese Case-Hardening Steels with Additions of Silicon, Chromium or Vanadium, and Their Behaviour in Practice.** H. Kallen and F. Meyer. (Technische Mitteilungen Krupp, Forschungsberichte, 1939, vol. 2, Dec., pp. 215-222). The authors state that German manufacturers are already using manganese steels with small additions of silicon, chromium or vanadium as substitutes for chromium-molybdenum steels (*see preceding abstract*). The present authors discuss the experience gained with some of these substitute steels as used for various parts of machinery, and reproduce curves showing the tensile strength, elongation and reduction in area of numerous specimens.

**Chromium Steel Castings.** E. K. Smith. (Metal Progress, 1940, vol. 37, Jan., pp. 49-54). The author gives a number of examples of the successful employment of steel castings containing the following amounts of chromium: 2% or less; 3%; 4-6%; 15% with 35% of nickel; 18% with 8% of nickel; 29% with 9% of nickel; 21%; 24%; 29% with 2.5% of nickel; and 3% with 13% of manganese. In some cases small percentages of vanadium or molybdenum are also present.

**The Nickel-Free Stainless Steels.** L. Sanderson. (Industrial Chemist, 1940, vol. 16, Jan., pp. 40-42). The author discusses the progress made in the development of chromium steels containing either little or no nickel. He deals first with the chromium-manganese-iron alloys and states that four types have now become recognised: The analyses of these are:

	(1)	(2)	(3)	(4)
	%.	%.	%.	%.
Carbon . . . . .	0.1	0.1	0.1	0.1
Manganese { . . . . .	18.0	9.0	9.0	18.0
Chromium . . . . .	9.0	18.0	16.0	10.0
Molybdenum . . . . .	1.0	...	...	...
Nickel . . . . .	1.0	1.0	2.0	...

The first three of these are corrosion-resistant and the last one is heat-resistant. In the second part of his paper he discusses the properties of some non-austenitic chromium-copper stainless steels,



developed by W. P. Digby, which contain 10% of copper and 18% of chromium. These are known as "cypritic" steels and it is claimed that they represent a cheap and effective alternative to the more costly nickel-chromium stainless steels.

**Stainless Steel for Aircraft Structures.** H. W. Perry. (Aircraft Production, 1940, vol. 2, Feb., pp. 35-37). The author compares some of the properties of stainless steel with those of aluminium alloys, with special reference to the application of these materials to aircraft construction. He also discusses the design of stainless-steel aeroplane wings, control surfaces and fuel tanks, as developed by the American firm Fleetwings Incorporated.

**Investigations of Iron-Rich Chromium-Manganese Alloys.** H. Legat. (Metallwirtschaft, 1940, vol. 19, Jan. 26, pp. 59-65; Feb. 2, pp. 79-82). The author reports on his investigation of the structure, notch-bar sensitivity, Brinell hardness and magnetic properties of seventy different chromium-manganese steels the analyses of which lay within the following limits: Carbon 0.03-0.22%, chromium 0.15-23.06% and manganese 0.44-35.00%. Having regard to certain similarities in their properties these alloys could be classified into seven groups as follows: (1) Ferritic to martensitic alloys; (2) martensitic-austenitic alloys; (3) austenitic alloys; (4) ferritic-martensitic to ferritic-austenitic alloys; (5) ferritic-austenitic alloys with the formation of solid solutions; (6) untransformed ferritic alloys; and (7) non-austenitic alloys with the formation of solid solutions. From the results obtained he constructs a diagram of the iron corner of the iron-chromium-manganese system at room temperature, 900° C., 1100° C. and 1300° C.

**The Physical Properties and Heat Treatment of Chromium-Silicon-Vanadium Steel E/172.** I. I. Bornatskiy. (Metallurg, 1939, No. 8, pp. 50-59). (In Russian). The steel studied, which is intended as a substitute for high-speed steel, had the following composition: Carbon 1.04%, manganese 0.28%, silicon 1.65%, chromium 11.25%, vanadium 2.5%, phosphorus 0.017% and sulphur 0.015%. The investigation included the determination of the critical points, a study of the martensite transformation, a study of the ageing of supercooled austenite and an examination of the influence of the quenching and tempering temperatures on the microstructure and hardness of the steel. The higher the carbon and chromium contents of the steel, the lower is the position of the martensite point as compared with high-speed steel. Ageing of the supercooled austenite is most marked at above 650° C., while it is relatively stable at below 550° C. Ageing treatment of the austenite should be included in the heat treatment as this makes the transformation of the retained austenite into martensite more complete during subsequent repeated tempering. Dissolution of the carbides is slower whilst grain growth is more intense at the quenching temperature in the case of E/172 as compared with high-speed steel.

Maximum hardness (Rockwell C 62-63) is obtained by quenching from 1225-1250° C. and triple tempering at 500° C. The steel must be held one and one-half to twice as long at the quenching temperature as compared with high-speed steel. It has less tendency to oxidise during heat treatment than high-speed steel.

**Manganese in Carbon Steels.** B. Thomas. (Metallurgia, 1940, vol. 21, Jan., pp. 73-75). The author presents the results of a series of bend tests the object of which was to ascertain the influence of a difference of 0.14% of manganese on the properties of steel both in the hardened and unhardened state. The analyses of the two basic open-hearth steels used were : Carbon 0.54% and 0.53%, manganese 0.67% and 0.81%, sulphur 0.036% and 0.052%, phosphorus 0.031% and 0.038%, and silicon 0.141% and 0.138%, respectively. The tests were made by resting test-pieces about  $\frac{1}{8}$  in. thick on bearers having 6-in. centres and applying loads in suitable gradations until either 1 in. of elastic movement was recorded or fracture took place. In the following conclusions the normal manganese steel is referred to as "A" and the high-manganese steel as "B" : (1) The difference of 0.14% of manganese was sufficient in the strips under test to cause two out of three of the B specimens to fracture under load, whilst none of the A strips attained such hardness ; (2) for three heat-treated specimens, an average of 54.7% greater load was required to terminate the tests in the case of B as compared with A ; and (3) in connection with resilience, the minimum average loading required to produce a permanent set was 117 kg. in the case of A, and 150 kg. in the case of B, whilst the average of the final permanent set figures obtained at the conclusion of the tests was 0.55 in. with A in comparison with only 0.27 in. for those with B. From this it is seen that the A steel had less than half the resilience of that of B.

**Contribution to the Problem of the Effect of Ladle Additions on the Properties of Cast Iron.** E. Piwowsky. (Giesserei, 1940, vol. 27, Jan. 20, pp. 21-30 ; Feb. 9, pp. 47-52). After a chronological survey of methods of improving the properties of iron castings by additions of elements or compounds to either the charge in the cupola or the metal in the ladle, the author gives a detailed account of an investigation he undertook with the object of determining the influence of the usual ladle additions such as ferro-silicon, silico-calcium, titanium-silicon and calcium-lithium on the structure of a series of high- and low-carbon irons, and in what manner these changes in structure affected the mechanical properties. The following is a summary of the conclusions reached : (1) There is little to choose between raising the silicon content of a high-quality iron refined in an electric furnace by either ladle additions of ferro-silicon and silico-calcium or cupola additions of ferro-silicon ; (2) ladle additions to iron produced from pig-iron and cast-iron scrap have, on the whole, a deoxidising effect and this seems to produce a more dense structure, but this has only a

slight effect on the strength properties; (3) the strong graphitising effect of these ladle additions can be used to keep down the silicon content of this high-quality iron and this reduces the influence of the wall-thickness on the strength per unit of cross-section; (4) the addition of increasing quantities of steel scrap to the charge has a better effect than ladle additions on the process of carbon pick-up by high-quality iron in the cupola; (5) ladle additions have the greatest effect when used with iron containing less than 2.8% of carbon produced from a charge containing a high percentage of steel scrap; (6) ladle additions do not reduce the size of the graphite particles; (7) a reduction in the phosphorus content appears to reduce the size of the graphite; and (8) in making ladle additions their size and the time at which they are put in are very important, and it is essential that they are immediately immersed beneath the surface of the molten iron.

**A Modern Cast Iron—Meehanite.** E. M. Currie. (*Metallurgia*, 1940, vol. 21, Jan., pp. 63–66). The author draws attention to the difference in the properties of grey cast iron and of special cast irons, in particular, of Meehanite, an iron developed in America and produced by the addition of graphitisers to the molten metal in the ladle. He reproduces a table of the mechanical properties of iron produced by the Meehanite “A,” “B,” “C,” “D,” and “E” processes and compares these with the properties of grey iron, semi-steel and cast steel. In conclusion he describes some industrial applications of Meehanite.

**An Investigation into the Permissible Load-Carrying Capacity of Steel Wire Ropes for Hoisting, with Special Reference to Deep-Level Windings on the Witwatersrand Goldfields.** J. J. P. Dolan and W. G. Jackson. (*Proceedings of the Institution of Mechanical Engineers*, 1940, vol. 142, Jan., pp. 225–259). This paper appeared previously in the *Journal of the South African Institution of Engineers*, 1939, vol. 38, Nov., pp. 86–124. (*See p. 163 A*).

**New Metallurgical Laboratory.** (*Commonwealth Engineer*, 1939, vol. 27, Dec. 1, pp 167–169). A description is given of a new metallurgical laboratory opened by a Melbourne company in which mechanical testing, heat treatment, chemical analysis, microscopic examination and gauging can be carried out. This laboratory provides a valuable service, especially to the smaller industrial firms whose output is insufficient to justify a laboratory of their own.

## METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 210 A-213 A)

**The Utility of M. Niessner's Oxide-Print Process.** F. Neuwirth, R. Mitsche and H. Dienbauer. (Archiv für das Eisenhüttenwesen, 1940, vol. 13, Feb., pp. 355-358). The authors report on an investigation of the utility of Niessner's slag-print process for the determination of non-metallic inclusions in steel. The process itself has been previously described (*see* Journ. I. and S.I., 1937, No. II., p. 93 A). They found that it was quite suitable for this purpose, especially with regard to iron-oxide inclusions, as their number, distribution and approximate size could be determined. It remains to be ascertained, however, what are the smallest size of particle and the minimum proportion of iron which it must contain in order to be revealed by this process. Reproductions in colour of fifty-six slag prints are presented.

**Electrolytic Preparation of Iron and Steel Micro-Specimens.** G. E. Pellissier, jun., H. Markus and R. F. Mehl. (Metal Progress, 1940, vol. 37, Jan., pp. 55-56). The authors describe some tests they made using the method of electrolytic polishing developed by Jacquet and Rocquet applied to steel. They found that, after grinding the specimens and preparing them with 000 emery paper, the electrolytic part of the process required about 10 min. They append a data sheet giving particulars of the solution, current density, voltage, temperature and time required for the electrolytic polishing of carbon steels, Armco iron and white cast iron, austenitic steels, iron and silicon-iron and many non-ferrous metals and alloys.

**The Electrolytic Polishing of Some Alloys Containing Nickel and Chromium.** P. A. Jacquet. (Métaux et Corrosion, 1939, vol. 14, Oct., pp. 127-131). The author describes the technique for the electrolytic polishing of specimens of 18/8 stainless steel and of Inconel (nickel 80%, chromium 14% and iron 6%). He reproduces twenty-four micrographs of specimens prepared in this way, and shows that the technique is specially suitable for the study of the process of corrosion.

**Electron Defectoscope.** A. Gorelik, V. Smirnov and S. Samarin. (Vestnik Metallopromyshlennosti, 1939, No. 7, pp. 67-70). (In Russian). By designing a magnetic defectoscope for detecting faults in rails, at speeds of 10-25 km. per hr., the authors developed a new instrument for the detection of the local fields resulting from the scattering of the lines of force by defects. The essential part of the instrument is a thermionic valve in which the top of the glass bulb is flattened. The semi-cylindrically shaped anode has its concave surface turned towards the flat top of the glass bulb, the heated cathode wire filament being placed at the axis of the semi-



cylindrical anode and as near as possible to the flat surface of the bulb without overheating the glass. The valve is used upside down with the flattened top of the bulb near the surface of the part being examined. When moved along the surface of the part magnetised by means of any suitable D.C. magnetising system, the uniform magnetic field produces a constant effect on the electron stream from the cathode to the anode and consequently on the anode current of the search valve, while local variations in the magnetic field produce sudden changes in the anode current. The output of the search valve is amplified by applying it to the grid of an ordinary amplifying valve, the output of the latter being used to work an indicating device such as a milliammeter, a sensitive relay or an oscillograph. By adjusting the grid bias of the amplifying valve, the effect of a steady magnetic field on the output of the search valve is neutralised and the indicating device made to work only when a flow causes a sudden change in output. Tests have shown that with this instrument it is possible to detect defects amounting to only a few tenths of one per cent. of the total section of the rail. The other advantages of the electron defectoscope are that it is independent of the speed at which it is moved over the object and the ease with which its sensitivity can be varied by adjusting the anode and filament potentials of the search valve.

**Practical Experience in the Application of the Magnetic Powder Method for the Discovery of Cracks.** H. Schrader. (Materials Committee of the Lilienthal Gesellschaft, June, 1939 : Technische Mitteilungen Krupp, Forschungsberichte, 1939, Anhang, pp. 18-28). The author presents the results obtained with the magnetic powder method of detecting cracks in aeroplane-engine crankshafts and other parts, and discusses the sensitivity of the process in relation to the width of the crack and to the distance of the crack under the surface. He points out that the usefulness of the process is largely dependent on the skill of the operator, and that it must not be assumed that every accumulation of powder indicates a crack, so that other metallographic methods of examination must sometimes be employed to supplement the magnetic method.

**Applications of X-Ray Technique to Industrial Laboratory Problems.** H. P. Rooksby. (Journal of the Royal Society of Arts, 1940, vol. 88, Feb. 16, pp. 308-336). After explaining in simple terms the theory of radiography, the author describes many of its industrial applications. For this purpose he divides the use of the X-ray diffraction pattern into the following six groups which are in accordance with the states or attributes of materials which lend themselves to examination by this technique: (1) Identification of the chemical compound or compounds present; (2) distinction between different crystalline forms of the same chemical compound; (3) formation of solid solutions and alloys; (4) the crystal size or state of subdivision of a material; (5) the presence of lattice distortion; and (6) fibre structure.

**Pseudomorphism in the Structures of Quenched and Tempered Railway Tyre Steel.** I. Frantsevitch, M. Borushko and L. N. Lashko. (Stal, 1939, No. 7, pp. 51-60). (In Russian). Previous investigators had suggested and shown that impact-brittleness in tyres was connected with the presence of sorbite with martensitic pseudomorphism and that this in turn was connected with the rolling, and more particularly with the quenching temperatures. In the present research the conditions for the formation of this type of structure were studied in laboratory experiments on 0.52% carbon steel. After being subjected to different quenching and tempering treatments the specimens were examined metallographically by X-rays (photographing on isopanchromatic plates through filters in order to distinguish the different intermediate structures) and by hardness tests. In addition, the lattice distortion of  $\alpha$ -ferrite in specimens annealed at different temperatures was studied. The temperature at which softening of compressed specimens occurred was also determined. The formation of quenching cracks in specimens quenched in different media from different temperatures was investigated, and finally, compression tests were made to determine the plastic properties of sorbitised specimens with both a regular sorbitic structure and a sorbitic structure with martensitic pseudomorphism. A detailed discussion, based on the experimental data, is presented of the quenching and tempering process with reference to the genesis of pseudomorphous formations in the tempered structures. Apart from the fundamental causes for the transformation of martensite into a heterogeneous mixture of  $\alpha$ -ferrite and cementite, heterogeneities in the metal and oxygen content are regarded, under certain conditions of heat treatment, as factors favouring the occurrence of pseudomorphism in sorbite and of shrinkage cracks. The stages of the transformation of the martensite lattice were determined by X-ray analysis and also demonstrated by corrosion tests. The need to raise the temperature range of heat treatment (maximum temperature about 950° C., for the development of sorbite with the object of avoiding pseudomorphism and consequent brittleness is pointed out.

**The Role of Graphitisation Nodules in the Annealing of Malleable Cast Iron.** S. A. Saltykov. (Metallurg, 1939, No. 8, pp. 10-22). (In Russian). Earlier work indicated that graphitisation nodules were formed during cooling through the  $\gamma$ - $\alpha$  region by submicroscopic particles of graphite precipitating from the supersaturated solid solution, the number of nodules depending on the degree of supercooling. A modification of Schwartz's formula :

$$N = 2.38 n^{1.6}$$

is suggested for the number of nodules per cubic millimeter where  $n$  is the number of nodules per square millimeter of a section. From this, assuming a closely packed arrangement of

the nodules the mean distance  $c$  between them is given by the formula :

$$c = \frac{1}{1.1895 \sqrt[3]{n^{1.6}}}$$

(See also p. 164 A). The mean value of  $c$  gives some idea of the length of the path through which the carbon has to diffuse during annealing, though actually this length varies from zero at the beginning to  $c/2$  at the end of the process. Experiments on white cast iron with 2.7% of carbon and 1.3% of silicon using test pieces of different cross-section showed that there was a linear relation between the duration in hours of the first stage of graphitisation ( $T_1$ ), the duration in hours of the second stage ( $T_2$ ), and  $c$ , viz. :

$$T_1 = 118c \text{ and } T_2 = 31c,$$

the first stage of graphitisation being effected at 980° C. Rapid quenching and superheating both increase the number of graphitisation nodules and correspondingly shorten the time required for annealing. The author has shown that the number of nodules can also be increased by deoxidising the iron with silico-calcium in the ladle. In an iron with 2.67% of carbon, 1.23% of silicon, 0.51% of manganese and 0.113% of sulphur, an addition of 0.4% of silico-calcium increased the number of nodules from 5–12 to 124–168 per sq. mm. Some work by the author taken in conjunction with that of other investigators indicates that the elongation of malleable cast iron reaches a maximum somewhere between 120 and 1000 nodules per sq. mm. and then falls off, whilst the tensile strength appears to increase continuously. The impact strength of very rapidly annealed malleable cast iron (1200–2000 nodules per sq. mm.) does not differ from that of ordinary malleable iron with 20–50 nodules per sq. mm.

**Rapid Method of Determining Grain Size in Axle and Spring Steel.** G. P. Sobol'. (Zavodskaya Laboratoriya, 1939, No. 6, pp. 586–588). (In Russian). When preparing specimens for grain-size determinations good results were obtained by heating them to 940° C. for 60–70 min., cooling to 750° C. for 2–3 min., and then quenching in water at 40–50° C. in the case of axle steel, and in oil at 20–25° C. in the case of spring steel. Sections were then etched in a mixture of two parts of concentrated nitric acid, twenty-five parts of 4% picric acid and seventy-three parts of ethyl alcohol. The etched sections were examined under a microscope with magnification of 100 diameters and compared with the A.S.T.M. standard photomicrographs. Excellent agreement was obtained with the grain-size determinations by the McQuaid-Ehn method.

**The Standardisation of a Method of Evaluating Non-Metallic Inclusions in Steel.** I. N. Golikov and M. I. Vinograd. (Zavodskaya Laboratoriya, 1939, No. 7, pp. 710–713). (In Russian). By way

of introduction the nature of the non-metallic inclusions to be considered is discussed and a brief critical survey is made of the existing "scales" for their evaluation. The scale developed by the authors (which is illustrated) is applicable to wrought, plain, low-alloy and high-alloy structural and tool steels. The scale is divided into three groups covering brittle oxides, sulphides, plastic oxidic inclusions and carbides. The first two groups are subdivided into fine and coarse inclusions, the amount being indicated by a 1 to 5 system of marking. In practice, evaluation may exclude subdivision into fine- and coarse-grained inclusions as the marks are arranged to correspond either to a large number of small, or to an equivalent number of large, inclusions. The surface of the polished section must be in the direction of the grain and the area examined should not be less than 3 sq. cm.

#### **The Examination of a Fifteenth Century Wrought Iron Gun.**

A. Pomp and F. Spies. (*Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1940, vol. 22, No. 1, pp. 1-8). The authors report on an examination of a specimen cut from a wrought iron gun made in Styria in the fifteenth century. The results of chemical analyses are presented together with numerous macrographs and micrographs of the structure, and the method of manufacture is explained.

**A Theoretical Electron Law Relating to the Effect of Addition Elements on the Polymorphism of Iron.** H. Schlechtweg. (*Zeitschrift für Metallkunde*, 1940, vol. 32, Jan., pp. 18-20; *Technische Mitteilungen Krupp, Forschungsberichte*, 1940, vol. 3, Feb., pp. 45-47). The author reviews briefly Wever's method of classifying atomically those alloying elements which, when added to iron in small quantities, raise or lower the  $A_3$  point. He then attempts to link Wever's results with the quantum picture of the structure of atoms. The several alloying elements are discussed from this point of view.

**The Transformations in Manganese Steels.** F. Wever and K. Mathieu. (*Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung*, 1940, vol. 22, No. 2, pp. 9-18). In their investigations of the transformations in steels containing manganese 2% to 5% and carbon up to 1.4% the authors observed that there were three stages. They describe and discuss the influence of alloying elements on the temperature, velocity and nature of the transformations. In the ternary iron-manganese-carbon system the martensite points lie in a surface which is defined by the martensite lines of the iron-carbon system and the lines of the irreversible  $\gamma$ - $\alpha$  transformations of the iron-manganese alloys. The authors describe the relationship of these stages of transformation to the intermediate stage, and show that various carbides are formed in the pearlite and intermediate stages. They construct a diagram showing the transformations during the undercooling of manganese steels.



## CORROSION OF IRON AND STEEL

(Continued from pp. 166 A-167 A)

**Report on Corrosion Research Work at Cambridge University Interrupted by the Outbreak of War.** U. R. Evans. (Iron and Steel Institute, 1940, *see* this Journal, Section I.). A description is given of researches by a group of investigators interrupted by the war; the results obtained up to September, 1939, are summarised, and interpretations—necessarily tentative—are suggested. Agar's exploration of the potential distribution close to the surface of zinc partly immersed in chloride or sulphate solution showed definitely that electric currents were passing between a cathodic zone, situated in the well-aerated region at the meniscus, and an anodic zone below it. Visible corrosion was always associated with the zone which the electrical apparatus showed to be anodic. From the distance between equipotential lines, the strength of the currents could be calculated. It was found that these were strong enough to account for at least the greater part of the corrosion—and probably for the whole of the corrosion leading to loose corrosion product (the small amount of adherent corrosion product has a different origin). The researches had not proceeded far enough to ascertain whether there was an exact equivalence between current strength and corrosion rate, but they have established the fact that the attack is at least mainly electrochemical.

A convenient criterion of the protective character of a film is the amount of acid which must be added to copper nitrate to cause deposition of copper when a drop is placed on an iron surface. The author's comparative tests on heat-tinted and other specimens of carbonyl iron have confirmed the belief that iron carrying interlocked oxide is better protected than iron carrying somewhat thicker films, where the interlocking is less. The tracing of a scratch-line with a weighted needle on tinted iron did not, in general, perceptibly increase the susceptibility to attack, provided that there was a short exposure to air before the placing of the drop on the surface. But specimens which had been kept two years in a desiccator after tinting showed a significant increase of susceptibility when freshly scratched.

Mayne's attempts to obtain, by means of water-emulsification, a rust-inhibitive priming paint suitable for application (*a*) to steel wet with water, and (*b*) to steel partly weathered so as to carry broken scale, rust and iron salts, appear to have succeeded, so far as objective (*a*) is concerned, although prolonged outdoor tests will be needed before definite claims can be made. At the time of the outbreak of war, objective (*b*) had not been obtained.

Gould's work on corrosion-fatigue, of which an account had been published early in 1939, was continued up to the outbreak of war; the chief new results concerned the prevention of corrosion-fatigue by means of zinc ribbon, even in cases where the steel surface was not completely covered up. This was effective in the case of chloride solutions, but less so in the case of typical tap water, owing to its lower electrical conductivity.

Hoar's results on the influence of the steel base on the corrosion of tin cans containing fruit were also published in 1939; this work is still being continued.

**Some Recent Studies of Thin Oxide Films on Metals.** W. H. J. Vernon. (Chemistry and Industry, 1940, vol. 59, Feb. 10, pp. 87-88). The author surveys recent research at the Chemical Research Laboratory at Teddington on thin oxide films on zinc, high-purity iron and mild steel. He refers to the work carried out by Wormwell, Nurse and himself on the thickness of oxide films on steel in relation to their colour, in the course of which the following values were obtained for total thickness of the material (*i.e.*, including the continuous secondary film and the heterogeneous primary layer underneath): (1) First-order straw: 350 Å (calculated on apparent area of specimen), 140 Å (estimated real area); and (2) first-order blue: 590 Å (apparent area) and 140 Å (estimated real area). Both the colour of the heated specimen and the thickness of the film removable by stripping were found to be almost the same whether the specimen was freshly cleaned or whether a relatively thick primary film had previously been formed on the specimen by long-continued exposure at 25° C. This suggests that the iron in the film responsible for the interference colours diffuses outwards from the basis metal.

**Ferroxyl Indicator in the Investigation of Corrosion.** A. S. Afans'ev and L. N. Novikova. (Zavodskaya Laboratoriya, 1939, No. 6, pp. 637-639). (In Russian). The authors describe suitable indicator compositions and the various ways of using them for the study of the polarities of different parts of the surface of corroding specimens of iron.

**Corrosion in Central Heating Installations and Its Prevention.** H. Klas. (Stahl und Eisen, 1940, vol. 60, Jan. 18, pp. 41-48). The author examines and discusses the appearance and causes of the internal corrosion of hot-water pipes and presents curves showing the relation between the rate of corrosion and the temperature of the water, as well as that between the solubility of oxygen in water and the pressure and temperature. He gives some approximate figures of the costs of phosphate and sulphide treatment plants, and, in conclusion, considers the relative effectiveness of enamel, cement and organic coating materials for the inside of mild steel tubes.

**The Investigation of Soils in Relation to the Protection of Pipes against External Corrosion.** C. M. Tiemersma-Wichers. (Kor-

rosion und Metallschutz, 1940, vol. 16, Jan.-Feb., pp. 39-44). Working on the principle that it is immaterial how corrosive a soil may be as long as it can be prevented from acting on the pipes buried in it, the author investigated the properties of a number of sand, soil and clay mixtures with a view to finding one which, when applied to the external surface of pipes, would effectively prevent the attack of corrosive soils on the pipes. He presents the results of many tests in which the effects of changes in the porosity, plasticity, grain size, specific gravity and moisture content on the protective value of the mixture are demonstrated. His general conclusion is that a clay, made up to an even consistency in a mill and mixed with 5% of cement to strengthen it, forms a very good coating. The clay must be tamped as evenly as possible all round the pipe.

**The Activation and Passivation Potentials in Passivation Phenomena.** V. Cupr. (Korrosion und Metallschutz, 1940, vol. 16, Jan.-Feb., pp. 10-17). The author discusses the results obtained in a series of experiments in which the changes of potential occurring during the passivation of chromium electrodes by oxygen and ozone were measured. The tests showed that the auto-activation of chromium and ferro-chromium electrodes took place when a certain potential was reached which had a more positive value than that attained by external cathodic polarisation of the same electrode under the same conditions. Similarly, the auto-passivation of the electrodes produced by the oxidising effect of either oxygen from the air or ozone took place when a potential was reached which had a more negative value than that attained by external anodic polarisation.

**A Theory for the Passivity of Chromium.** M. A. Ryan and H. Heinrich. (Electrochemical Society, Apr., 1940, Preprint No. 10). The authors formulate a theory for the passivity of chromium which is based on its electronic structure. According to this theory the atoms on the face of each unit cube of passive chromium share the electrons in their outermost orbits in such a way as to bring about a stable condition, *i.e.*, passivity.

**X-Ray Analysis of Corrosion Products from Galvanised Sheets.** F. R. Morral. (Electrochemical Society, Apr., 1940, Preprint No. 12). The author presents the results of an X-ray diffraction analysis of the products formed by corrosion on galvanised steel sheets; this showed the presence of certain zinc salts including  $\text{ZnO}$ ,  $\text{ZnCO}_3$ , and  $2\text{ZnCO}_3 \cdot 3\text{Zn(OH)}_2$ . The rate of corrosion and the exact composition of the products depends on the composition of the original coating and the nature of the atmosphere in which it is exposed.

## BOOK NOTICES

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(Continued from pp. 216 A-217 A)

AMERICAN SOCIETY FOR METALS. "*Modern Steels. Manufacture, Inspection, Treatment, and Uses.*" A series of lectures organised by the Pittsburgh Chapter. Edited by Ernest E. Thum. 8vo. Pp. 374. Illustrated. Cleveland, Ohio, 1939: American Society for Metals. (Price \$3.50.)

Metallurgists in this country have come to have a very high regard for American contributions to published work on the science of metallurgy, and among these the volumes sponsored in recent years by the American Society for Metals take a very high place.

This admirably produced book left the reviewer curious as to the nature of the audience to which the lectures were originally delivered. In print the impression created is something like that of the Christmas lectures at the Royal Institution, in that one is convinced of the scientific eminence and competence of the lecturers, but is conscious that some of their ability has gone to make an abstruse subject clear to those less well equipped to understand. No aspect of the subject is beyond the exposition of the distinguished contributors, and the most modern conceptions of the metallurgist and the most recent theories concerning the microstructure of steel are dealt with in simple but accurate terms.

There are thirteen chapters, each contributed by a specialist, many of whom are well known from other published work, and the subjects covered include steelmaking processes, hot working, inspection and testing, metallography, heat treatment, and special steels, some of these occupying several chapters by one author. The simplicity of the style does not detract from the value of the text, and all but the most knowledgeable metallurgists will find much to interest them, and all readers are provided with an easily digested summary of the results of much modern research work that must otherwise be consulted at much greater length in original papers.

The publications of the American Society for Metals are noted for their lavish and excellent illustrations, and in this respect the present volume maintains the standard already set. The micrographs are excellent, the diagrams clear and informative, and there are numerous valuable tables and summaries of the kind already made familiar in other of the Society's publications as "data sheets."

The net result of the scope and style of the work is that an unusual type of textbook is provided. In some sections, owing to the limitations imposed on the original lecture, no great detail is possible, but in all the chapters the subject is developed simply and clearly, until the latest conceptions are capable of being followed with little difficulty. To amplify the substantial groundwork provided by the contributors, the editor has included a bibliography of supplementary reading at the end of each chapter, and reference to this should present few difficulties if the present volume has been read with care and attention.

A feature that calls for some mention is a section of exercises at the end of each chapter, designed to test the reader's grasp of what he has read. These lists of questions may be representative of modern examination technique in America, but they look strange to those familiar with conventional examination papers in this country, and many of the items are couched in highly unprofessional terms.



This type of book cannot be said to fill a want, but there is no doubt that all metallurgists who read it will profit by their study, and will find pleasure in the easy way in which the ramifications of modern steel metallurgy and metallography are explained and clarified.

STEPHEN L. ROBERTON.

HUDSON, J. C. "*The Corrosion of Iron and Steel.*" Being a general account of the work of the Corrosion Committee of the Iron and Steel Institute and the British Iron and Steel Federation. With an Introduction by Dr. W. H. Hatfield, F.R.S., Chairman, and Dr. T. Swinden, Vice-Chairman of the Corrosion Committee. 8vo. Pp. xv + 319. Illustrated. London, 1940: Chapman and Hall, Ltd. (Price 18s.)

One of the most valuable aids in the promotion of scientific research is the pooling of knowledge, not only between research workers of any one country, but also between those of different nationalities. This has been one of the foremost thoughts in the minds of the research committees of the Iron and Steel Institute and the British Iron and Steel Federation, and care has been taken to place copies of all Reports containing accounts of the work of the different committees in the chief University and Scientific Libraries throughout the world for the benefit of research workers. With the publication of Dr. Hudson's book the Corrosion Committee has gone a step further, and has made available a work on the important subject of corrosion, written in such style that it can be read with interest and benefit by engineers and those engaged in the metal industries who have had little or no chemical and metallurgical training. Further, it has been realised that the original voluminous reports of the Corrosion Committee (five in number), necessarily written in great detail, might prove too bulky to enable those in search of information, but with limited time to spare, to pick out the essential data required. Therefore, the present work serves two purposes.

The author explains in his preface that only a selection of the experimental results is presented, and these are expressed in simple units. This treatment has the drawback that in some places the conclusions reached may not appear to be fully substantiated by the actual data adduced, but this is more than compensated for by the facts that the results are rendered more intelligible and the reader is spared the study of much bewildering detail and explanatory matter.

The book contains the following chapters: I. The Economic Evil of Rust; II. The Work of the Corrosion Committee; III. The Significance of Rolling Scale in the Rusting Process with Some Notes on the Oxidation of Iron and Steel at Elevated Temperatures; IV. The Rusting of Unprotected Iron and Steel in the Atmosphere; V. The Prevention of Rusting in the Atmosphere by Means of Paints; VI. Protective Coatings for Iron and Steel; VII. The Rusting of Iron and Steel When Immersed in Sea Water; VIII. The Rusting of Iron and Steel in Other Fields of Service; IX. Fundamental Research and Laboratory Work; X. Other Researches on Corrosion Conducted in Great Britain and Abroad; XI. What Remains to be Done in Preventing Rusting.

REMINGTON, J. S., and F. L. JAMIESON. "*Metallurgical Analysis and Assaying.*" 8vo. Pp. vii + 101. London, 1939: The Technical Press, Ltd. (Price 5s.)

In their preface the authors state that the object of their book is to provide a concise and inexpensive guide for the use of junior analysts,

who frequently have to rely on typewritten instructions only. Unfortunately the contents of the book might well be taken to be a collection of such typewritten instructions, and although the price of the book may be low, it is not cheap if the limited scope and size of the work be considered.

The methods given are for the most part standard procedures, and should certainly give satisfactory results where the highest accuracy is not essential. With few exceptions it is assumed that ores will be the starting-point of the assay, and the authors have thereby imposed a severe limitation on the use of their work, as the methods described may not be suitable for the estimation of a given element in an alloy. Incidentally, if the book is considered purely as a laboratory manual, it would have been more convenient to give the make-up of the necessary standard solutions beside the assays where they are required, rather than collected in a section by themselves. With a view, no doubt, to the class for whom the book is written, refinements of technique are generally avoided, and, apart from a section of equations at the end, no theory is given.

For the normal works chemist many of the methods given are not very rapid, and do not represent modern laboratory practice, and for the student there is no theory. In a field where there are already so many text-books the authors appear to have fallen between two or more stools in selection and presentation of the matter contained in the volume under review.

STEPHEN L. ROBERTON.

## FUEL

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(Continued from pp. 223 A-226 A)

**Heat Transfer in the Flow of Gas Through a Bed of Solid Particles.** O. A. Saunders and H. Ford. (Iron and Steel Institute, 1940, *see* this Journal, Section I.). The problem of the transfer of heat from a gas to a bed of solid particles is approached from first principles in order to relate the heat transfer to the shape and dimensions of the bed and particles, the physical characteristics of the material, the velocity and temperature of the gas, &c. It is shown theoretically that the heat transfer is governed by the dimensionless groups  $V\tau c'/lc$  and  $Vlc'/k$ , and by the shape of the bed and particles ( $V$  = mean linear velocity of the gas entering the bed;  $\tau$  = time;  $c'$  = specific heat of unit volume of gas at constant pressure;  $l$  = characteristic linear dimension;  $c$  = specific heat of unit volume of material of the particles;  $k$  = conductivity of the particles); also that  $Vlc'/k$  may be neglected if it is small enough, that is to say, if the size,  $l$ , of the particles is small enough, or their conductivity,  $k$ , large enough, for the effects of temperature differences in their interiors to be neglected; in such cases the thermal conductivity of the particles is of no importance. Once the validity of these groups has been checked experimentally, the results can be applied to the whole possible range of materials, provided that their physical constants are known.

Experiments to test out the theory are described, in which hot air was passed through beds of various depths of steel, lead, or glass spheres of diameter up to 0.25 in. It was found that the results for different sizes, velocities and materials could be correlated with  $V\tau c'/lc$ , indicating that the effects of temperature differences within the particles were negligible in the experiments. Curves are given for calculating the variation of gas temperature through a given bed at any given moment. It is shown, for example, that the time taken to attain a given temperature at a given depth of bed is directly proportional to the specific heat and density of the particles, inversely proportional to the gas velocity, and only slightly affected by changes of particle size. Curves are also given for the heat transfer. The highest value of  $Vlc'/k$  in the experiments was about 4, corresponding to diameters of 0.25 in. and 11 in. for glass and steel, respectively, at an air speed of 2 ft. per sec. The results are, therefore, applicable up to these sizes; how far they are valid for larger sizes remains to be found by further experiments, but rough calculations show that the errors in using them up to sizes two or three times those quoted are probably only a few percent.

Although only part of the ground has been covered in the present experiments, it is hoped that the methods developed will in due course be extended to cover the whole field, and eventually include the more complicated conditions found in industrial plant.

**The Application of Rational Analysis to Some Typical African Coals.** G. K. Morrison. (Journal of the Chemical, Metallurgical and Mining Society of South Africa, 1939, vol. 40, Dec., pp. 201-212). After discussing methods adopted in other countries for the classification of coal, the author considers what method should be employed for classifying South African coals. Francis and Wheeler have recognised four main ingredients in coal, *viz.*, hydrocarbons and resins, organised plant entities, ulmins, and fusain, and they have found that the reactivity of the ulmins towards oxygen can be related to maturity. In the present paper the author describes the extraction of coal with pyridine and the full rational analysis of four different types of South African coal.

**Notes on Specific-Gravity Coal-Washing, with Special Reference to the Tromp Process.** C. W. H. Holmes. (Transactions of the Institution of Mining Engineers, 1940, vol. 98, Feb., pp. 175-194). (See p. 173 A).

**Notes on the Conversion of a Coal-Washing Plant at the Société Anonyme des Charbonnages de la Louvière et Sars Longchamps, at Saint-Vaast.** M. Cambier. (Revue Universelle des Mines, 1940, vol. 83, Feb., pp. 46-56). The author describes how the reconstruction of a coal-washing plant was carried out at a French colliery, a reconstruction which not only improved the throughput from 100 to 175 tons per hr., but also increased the proportion of screened nuts and decreased that of the fines.

**Centralised Control of a Coal-Washing Plant.** (Engineering, 1940, vol. 149, Mar. 8, p. 250). A description is given of the control system for the electric motors at a coal-washing plant of Glass Houghton and Castleford Collieries, Ltd. (See p. 223 A).

**The Coking Industry of 1939.** G. E. Foxwell. (Coke and Smokeless-Fuel Age, 1940, vol. 2, Feb., pp. 28-34). The author reviews the state of development attained in 1939 by the coking industry of Great Britain, and describes some of the coke-oven batteries and by-product plants which were completed in that year.

**The Influence of the Past upon the Coke-Oven of Today.** C. Otto. (Blast Furnace and Steel Plant, 1940, vol. 28, Jan., pp. 53-56, 96, 97). The author traces the development and improvements in coke-oven design from 1620, when the beehive oven in its original form was used in England, up to the present time. His paper is illustrated with 23 drawings showing various stages of improvement from the Coppee oven of 1861 onwards.

**Coke and By-Product Yields from Various Coals.** J. D. Davis. (Iron and Steel Engineer, 1940, vol. 17, Feb., pp. 47-61). The author describes some of the work done and the results obtained during an investigation of the yield and quality of the products of



low-, medium-, and high-temperature carbonisation of American gas and coking coals. The method of testing adopted was that known as the Bureau of Mines and American Gas Association method.

**Production of Low-Temperature Coke by the Disco Process.** C. E. Leshner. (American Institute of Mining and Metallurgical Engineers, 1940, Technical Publication No. 1176). The author describes the Disco process of low-temperature carbonisation as developed by the Pittsburgh Coal Carbonization Co. using Wisner's patents. The coal used is cleaned and ground to below  $\frac{3}{8}$  in. It passes over a series of horizontal conveyors in a roaster which brings the temperature up to 600° F., and thence into an inclined rotary carboniser 6 ft. in dia. by 91 ft. long, heated by gas (at about 1000° F.) passing through an annular space surrounding it. The coke is produced in ball form and is marketed for household use in two sizes, 1-2 in. and 1-6 in. The present plant operating with three carbonisers produces about 7000 tons of coke and 140,000 gal. of tar per month. An extended abstract of this paper is given in *Iron and Coal Trades Review*, 1940, vol. 140, Mar. 22, p. 477.

**The Combustibility of Coke.** H. M. Finniston. (*Journal of the West of Scotland Iron and Steel Institute*, 1939, vol. 47, Nov., pp. 15-31). The author describes part of the work of the Scottish Coke Research Committee on their study of the function of coke in the blast-furnace. In the first part of this paper the author describes the apparatus and procedure for estimating the surface activity of samples of coke when allowed to proceed nearly to equilibrium in various gaseous atmospheres. The experiments were expected to translate into quantitative measurement the conception that the reactivity of coke was due to successive reactions, tending to equilibrium, effected primarily at the boundary of the solid-gas system. In the second part he describes a method for the quantitative measurement of combustibility which depended on a continuous weighing of a massive coke sample at constant temperature and under controlled air supply.

**The Use of Coke Breeze in Producers.** (*Coke and Smokeless-Fuel Age*, 1939, vol. 1, Dec., pp. 209-210; 1940, vol. 2, Jan., pp. 16-17; Feb., pp. 38-41, 44). The possibilities of utilising coke breeze in step-grate gas producers are discussed in the first part of this article, whilst the remaining two parts are devoted to descriptions of the design and operation of the Koppers, the Wellman-Galusha and the Power-Gas types of producer. Details of production, consumption and costs are also given.

**Facilitating the Metering of Gas and Air with Orifice Plates.** G. Neumann. (*Archiv für das Eisenhüttenwesen*, 1940, vol. 13, Mar., pp. 375-386). In this mathematical discussion the author presents, and explains the application of, a number of nomographs, curves and tables which simplify the calculations used in the design of orifice plates for the metering of fuel gases and blast.

## PRODUCTION OF IRON

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(Continued from pp. 227 A-229 A)

**Inland Rebuilds First Stack.** (Iron Age, 1940, vol. 145, Feb. 8, p. 43). Some particulars are given of the reconstruction and increase in the dimensions of the No. 1 blast-furnace of the Inland Steel Co., Indiana. The furnace was originally built in 1906, and produced about 500 tons of pig iron per day. After rebuilding it was blown-in in December 1939, and now produces 700 tons per day.

**Comparative Values of Iron Ore at the Blast Furnace.** G. W. Hewitt. (Blast Furnace and Steel Plant, 1939, vol. 27, Dec., pp. 1231-1237; 1940, vol. 28, Jan., pp. 50-52, 70). Taking a Lake Superior ore containing iron 51.5%, manganese 0.70%, phosphorus 0.060%, silica 7.3% and alumina 2.0% as a theoretical basis, the author presents a series of calculations which are examples of methods of evaluating Great Lake ores actually received from the amounts by which they differ from this basis.

**The Determination of Certain Characteristic Data from the Composition of Blast-Furnace Flue Gases.** A. Sarkisyants. (Stal, 1939, No. 8, pp. 1-8). (In Russian). The study of the working of a blast-furnace on the basis of the composition of the flue gases and the possibility of determining the composition of these gases from the composition of the burden are considered. The following values form the starting points of the calculations: (1) The amount of oxygen removed from the burden during reduction; (2) the amount of carbon passing into the gas; and (3) the composition of the flue gas. In order to determine the first two, it is necessary to know: (a) The state of oxidation of the iron and manganese in the burden; (b) the amount and composition of the scrap, limestone, coke and blast; and (c) the amount and composition of the iron, slag and flue dust. A number of detailed practical examples illustrate the method of calculation.

**The Manufacture of Ferro-Molybdenum.** (Journal du Four Electrique et des Industries Electrochimiques, 1939, vol. 48, Dec., pp. 361-362). A brief description is given of the production of ferro-molybdenum from molybdenite in the electric furnace.

**The Preparation of High-Purity Iron on a Large Laboratory Scale.** F. Adcock. (Journal of the Society of Chemical Industry, 1940, vol. 59, Feb., pp. 28-31). Commercial electrolytic iron is converted into ferrous chloride; this when treated with superheated steam yields iron oxide; from this hydrogen reduction and vacuum fusion produce high-purity iron at a rate of 500 g. per day.

## FOUNDRY PRACTICE

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(Continued from pp. 230 A-232 A)

**Use of Fluorspar in Cupola Operation.** A. Carsten. (Iron and Steel, 1940, vol. 13, Feb., pp. 139-142). The author discusses the theoretical and practical aspects of the effects of adding fluorspar to cupola charges. These aspects include the lime/fluorspar ratio, the influence of fluorspar on the viscosity of the slag, the sulphur content of the iron and the life of the cupola lining, and the importance of the size of the fluorspar lumps.

**The Causes of Accidents when Drawing Cupolas, and their Prevention.** E. Zweiling. (Giesserei, 1940, vol. 27, Mar. 22, pp. 98-99). The author describes some methods of fastening and releasing the bottom of a cupola, which can be operated from a distance, so that there is no risk of injury from the glowing mass which falls out when the cupola is drawn at the end of a melt.

**The Balanced-Blast Cupola and Fluidity.** W. Y. Buchanan. (Institute of British Foundrymen : Foundry Trade Journal, 1940, vol. 62, Feb. 8, pp. 113-114; Feb. 15, pp. 133-134). The author first quotes some figures from his previous paper on the balanced-blast cupola (*see* Journ. I. and S.I., 1936, No. I., p. 121 A), with particular reference to the charging technique and life of the lining. He then discusses more recent results and gives examples of the use of borings which prove that it is both possible and practical to melt borings in loose form. He then describes some advantages which have been gained by converting cupolas to the balanced-blast system, one of which is the increase in fluidity of the iron. The fluidity can be further improved by adding scale in the proportion of 6 oz. of scale to 60 lb. of molten metal. The making of moulds for fluidity tests is described in detail, and, in conclusion, the author deals with the effects of increasing the temperature, and of increased percentages of graphite, silicon, sulphur, phosphorus, lead and copper on the fluidity.

**A Study in Grey Cast Iron.** H. J. Young. (Journal of the Institution of Mechanical Engineers, 1940, vol. 140, Mar., pp. 55-60). The author surveys thirty years' experience of making grey iron for castings.

**The Scaling Loss when Melting in the Cupola.** R. Gerisch. (Giesserei, 1940, vol. 27, Mar. 8, pp. 77-81). The author discusses the losses which occur in the cupola process as determined by the difference between the weight of the metal charged and that of the castings produced. He analyses the causes of this loss in a

number of experiments with charges of different composition, and shows that the loss due to burning in the cupola is very small indeed and cannot be reduced to any appreciable extent by changes in cupola operation.

**Cast Iron for Modern Engineering Applications.** T. Tyrie. (Institute of British Foundrymen: Foundry Trade Journal, 1940, vol. 62, Feb. 22, pp. 155-156; Feb. 29, pp. 169-170; Mar. 7, pp. 185-187). In this general discussion of the production and properties of cast iron for general and particular engineering purposes, the author considers in turn the Lanz-Perlit hot-mould process, the inoculation process by which such irons as Meehanite and Ni-Tensyl are produced, the effects of alloy additions, melting practice and heat treatment for high-duty iron, mechanical properties, corrosion resistance, and expansion and thermal conductivity. An aluminium-chromium cast iron worthy of mention is that known as "Cralfer"; it has excellent heat-resisting properties and contains total carbon 3%, silicon 1%, manganese 0.6%, chromium 0.75% and aluminium 7.25%.

**Casts Steel Tractor Parts.** R. H. McCarroll and E. C. Jeter. Foundry, 1940, vol. 68, Feb., pp. 30-33, 86). **Casting Steel for Ford Tractors.** (Iron Age, 1940, vol. 145, Feb. 15, pp. 34-39). The authors describe some of the new equipment and the foundry technique at the Rouge Works, Dearborn, of the Ford Motor Co., where cast-steel tractor parts are made. This foundry was recently reorganised to permit steel castings to be poured continuously instead of intermittently, an object which was achieved by the use of electric holding furnaces and conveyor reels which bring the moulds directly to the pouring spouts.

**Sand Testing with Special Reference to Deformation.** W. Y. Buchanan. (Institute of British Foundrymen: Foundry Trade Journal, 1940, vol. 62, Mar. 14, pp. 199-202). The author discusses the testing of moulding sands by the methods of the American Foundrymen's Association and the British Cast Iron Research Association, with special reference to the factors affecting the amount of deformation of rammed test-pieces under increasing load. He describes different methods of measuring the deformation and of assessing the moulding quality of sands from data obtained by different tests.

**Gating and Feeding of Castings.** A. Johnson. (Iron Age, 1940, vol. 145, Feb. 22, pp. 26-28). The author describes the technique of gating and heading employed at a jobbing steel foundry making castings for oil-well machinery.

**The Displacement and the Fixing of Cores.** H. Hollweg. (Gieserei, 1940, vol. 27, Mar. 22, pp. 102-106). The author enumerates eleven different causes of the displacement of cores in moulds and describes suitable methods of dealing with them.

**Casting Ladles with Slag Separators.** J. Mehrtens. (Gieserei, 1940, vol. 27, Mar. 22, pp. 100-102). The author describes and illus-



trates a number of foundry ladles for molten iron which incorporate devices for holding back the slag.

**A Modern Foundry in Palestine.** A. Kremener. (Foundry Trade Journal, 1940, vol. 62, Feb. 29, p. 167). The author gives a brief description of a foundry plant set up in 1934 near Haifa, Palestine. There are two cupolas capable of melting 4 tons per hr., moulding machines, a fettling shop, a machine shop and an enamelling plant. The principal product is bath tubs, but other work is undertaken, and the author describes the moulds and casting technique adopted for making a number of high-pressure pipes 30 in. in dia. in 9-ft. lengths.

**The Foundry Industry of Poland.** G. Dickmann. (Giesserei, 1940, vol. 27, Feb. 23, pp. 61-64). The author reviews the state of development of the foundries in Poland, presenting statistics relating to geographical position, raw materials, productive capacity, men employed, &c. He outlines the steps which have been taken for the reorganisation of the industry in the German-occupied area.

**Practical Job Evaluation for the Small Foundry.** E. L. Roth. (Transactions of the American Foundrymen's Association, 1940, vol. 47, June, pp. 925-934). The author explains a method devised by Lott in 1926 for costing in a jobbing foundry. The method is based upon an analysis of the job into all the departments through which it passes and the allocation of marks for various factors which affect the time spent on it in each department; the total marks are then converted into cents at rates which depend on the wage rate applicable at the time.

## PRODUCTION OF STEEL

(Continued from pp. 233 A-236 A)

**Bredbury Steelworks.** (Iron and Steel, 1940, vol. 13, Jan., pp. 108-110). An illustrated description of the works of the Exors. of James Mills, Ltd., Stockport, is presented. This business was founded in 1850 for the manufacture of steel keys, and at the present time taper pins, grooved pins, ground shafting and a wide range of hot- and cold-rolled and bright-drawn sections are produced.

**The Continental Steel Corporation's Kokomo Plant.** C. Longenecker. (Blast Furnace and Steel Plant, 1940, vol. 28, Jan., pp. 58-68). The author traces the history of the growth of the Continental Steel Corporation and describes and illustrates the plant of the Corporation at Kokomo, Indiana. The plant includes open-hearth furnaces, a blooming mill, continuous bar mill, rod mill, wire-drawing machinery, and annealing, tinning and galvanising equipment. The works now has a productive capacity of 10,000 tons of wire products per month.

**Modernization of Existing Open Hearth Equipment.** G. L. Danforth, jun. (Iron and Steel Engineer, 1940, vol. 17, Feb., pp. 64-72). The author describes and discusses some improvements for increasing the efficiency of open-hearth furnaces and equipment. These include improved design of ports and doors, the use of welded instead of riveted ladles, increasing the capacity of cranes, improved ingot-stripping equipment and the operation of a waste-heat boiler.

**Preliminary Experiments on the Operation of Open-Hearth Furnaces with Blast-Furnace Gas Using Oxygen-Enriched Air.** G. Bulle. (Stahl und Eisen, 1940, vol. 60, Mar. 7, pp. 201-206). The author examines the possibilities of using blast-furnace gas and oxygen-enriched air for heating open-hearth furnaces, and describes some experiments undertaken with a 2-cwt. furnace. The results showed that on an experimental scale it was quite possible to produce steel using preheated blast-furnace gas and cold oxygen, or preheated blast-furnace gas and a preheated mixture of oxygen and air (50% of the total oxygen required being supplied by air and the other 50% by pure oxygen). The author outlines a plan for continuing the experiments on a large scale and gives information on the design of furnaces which are to be operated in this way. He discusses the costs and economic aspects of this method of heating.

**The Use of Nickel-Carbonyl Powder in the Melting Shops of the German Iron and Steel Industry.** P. Assmann and L. Schlecht.

(Stahl und Eisen, 1940, vol. 60, Mar. 14, pp. 226-227). After referring to the high-pressure carbon-monoxide process of producing nickel-carbonyl powder which was perfected in Germany in 1932, the authors describe how this powder is added to the charge in open-hearth and electric furnaces producing structural, stainless and heat-resisting steels.

**Manganese Equilibria in Steel Making from the Standpoint of the Electrochemical Theory.** P. Herasymenko. (Archiv für das Eisenhüttenwesen, 1940, vol. 13, Mar., pp. 369-372). In a previous paper the author put forward the theory that molten slags produced in steelmaking are electrolytically completely dissociated and contain practically no neutral molecules (*see* Journ. I. and S.I., 1939, No. I., p. 88 A). This hypothesis explains the manganese, silicon and chromium reactions which take place in the acid open-hearth furnace. In the present work the author shows that the above hypothesis also explains the reactions between molten steel and basic slags. The equilibria in which free cations such as  $\text{Fe}^{++}$  and  $\text{Mn}^{++}$  participate depend on the nature and concentration of the anions. In slags containing several types of anions the equilibrium constant  $K_{\text{Mn}}$  is a function of the sum of the concentrations of the separate anions. In the simplest case of a basic slag containing only  $\text{O}''$  and  $\text{SiO}_4''''$  anions, the equilibrium constant  $K_{\text{Mn}}$  can be obtained from the equation

$$K_{\text{Mn}} = (\text{O}'') \frac{K_{\text{Mn}}^b}{0.50} + (\text{SiO}_4''') \frac{K_{\text{Mn}}^s}{0.384}$$

in which  $K_{\text{Mn}}^b$  is the constant for the Fe-Mn-O system and  $K_{\text{Mn}}^s$  is the constant for the Fe-Mn-Si-O system, the latter saturated with silica.

**The Concentration of Free Iron Oxides in Basic Open-Hearth Slags.** P. N. Ivanov. (Metallurg, 1939, No. 9, pp. 9-14). (In Russian). In his introductory remarks the author criticises Schenk's theory of the free and combined iron-oxide contents of basic slags. It is impossible to calculate the free iron-oxide content of the slag, as it is connected with the oxidising capacity of the slag through such factors as the surface of contact between the slag and the metal and the total resistance to the diffusion of the oxide content, which factors cannot be determined. The free iron-oxide content of the slag was studied by examining the connection between the contents of iron oxides in the slag and its oxidising capacity (rate of elimination of carbon). From the data obtained it is concluded that when the basicity (as determined by the lime/silica ratio) is above 2.5 all the iron oxides in the slag may be regarded as being in the free state, as the calcium ferrites are immediately decomposed on contact with the molten metal. When the basicity is less than 2.5, part of the iron oxides becomes combined in the form of silicates. Herty's formula for the total iron oxide,  $\text{FeO} + 1.35 \text{Fe}_2\text{O}_3$ , can be used to calculate the free concentration of iron oxides in slags of normal and high basicity. The use of the modified Herty formula is not justified.

**Investigation of Gases Evolved During the Boiling of Open-Hearth Steel.** I. Kovalenko. (Zavodskaya Laboratoriya, 1939, No. 7, p. 753). (In Russian). A short illustrated description is given of the construction and use of a device employed for collecting samples of gas evolved during the boil. It consisted of a cylindrical bell-jar made of refractory material which was dipped into the steel, the gases being led away through a water-cooled tube attached to the top of the bell-jar.

**X-Ray Method for Rapidly Determining the Gas Evolution During the Melting and Teeming of Steel.** I. N. Frantsevich, M. S. Borushko, S. A. Kovalenko, N. F. Laskho, P. S. Rozdymakha and A. S. Tkachev. (Zavodskaya Laboratoriya, 1939, No. 9, pp. 953-956). (In Russian). Work carried out to adapt the X-ray method, suggested a few years ago, for the determination of the nature of the gas evolution during the melting of steel is described. A suitable composite, horizontal, chill mould was developed in which samples of metal were cast. Solidification was very rapid, the ingot being stripped 20 sec. after pouring. It was then cooled in water and X-rayed, the exposure being 16 sec. Rapid development enabled the fixed negative to be obtained 4 min. after the pouring of the sample. Experiments on larger ingots showed that while the general appearance of the gas inclusions was similar to that in the small test samples their absolute size was greater in the former ingots than in the latter. By way of illustration a series of X-ray photographs of samples taken at various stages in the course of melting and teeming a heat are reproduced. In conclusion a project of an open-hearth shop X-ray laboratory to carry out the above process is outlined with reference to a detailed plan.

**The Desulphurising of Pig Iron and Steel in Open-Hearth Practice.** V. Karmazin. (Stal, 1939, No. 8, pp. 9-17). (In Russian). The author presents a detailed consideration of the desulphurisation of iron and steel with many references to earlier work. After brief reference to desulphurising in open-hearth melting, the following aspects of the desulphurisation of the raw materials are discussed: (a) Pig-iron in ladles; (b) the desulphurising action of manganese; (c) treatment with alkalis; and (d) desulphurising of the fuel. The distribution of sulphur between the metal and the slag is considered, mention being made of the solubility of iron sulphide and of manganese sulphide and the interaction between them in the molten metal and slag. Desulphurisation with lime and manganese as well as the neutralisation of the effects of sulphur during deoxidation are dealt with next. Slag acts as an efficient desulphuriser when it takes up the sulphur in the form of manganese and calcium sulphides. To achieve this, the slag should contain sufficient free lime and manganous oxide and have a high temperature and fluidity (60-80 mm. by Herty's viscometer). The normal distribution coefficient of sulphur between metal and slag is 8, but this may fall to less than 4 if conditions are unfavourable. The author derives a number of



equilibrium and solubility constants, which throw some light on the mechanism of desulphurisation.

**Some Observations on the Duplex Process—Conversion of Basic-Bessemer Steel in the Electric Furnace.** (Journal du Four Electrique et des Industries Electrochimiques, 1939, vol. 48, Nov., pp. 335–340). Electric furnace practice in relation to the duplex process is discussed with particular reference to the best technique to employ to reduce the depth of pipe in the ingot head. Full details are given of the results obtained with several melts from a 20-ton furnace with and without the application of anti-piping compounds.

**Note on a Method of Improving Mild, Rimming, Basic-Bessemer Steel.** R. Lemoine. (Revue de Métallurgie, Mémoires, 1939, vol. 36, Dec., pp. 522–524). The author describes an improvement to the duplex process of steelmaking the object of which is to reduce the time and current consumption for the final refining in the electric furnace. The steel is blown in the Bessemer converter until the phosphorus content is 0.050%. The slag is poured off and ferro-manganese is added until the manganese is at 0.300%. The steel is poured into the transfer vessel or ladle, and a stream of prepared alkali mixture containing sodium carbonate and stabilisers is allowed to fall on the molten metal as it fills the vessel; this causes a violent reaction to take place, which is completed by the time the vessel reaches the electric furnace, and there is a pocket or trap in the ladle which prevents the products of the reaction from entering the electric furnace. The electric-furnace process is then worked with a slag which is only slightly deoxidising. The function of the electric furnace is then merely to bring the steel up to a good temperature for teeming and to adjust the manganese content. The treatment in the transfer vessel is strongly dephosphorising and slightly desulphurising, the former element being reduced from 0.050% to 0.020% and the latter from 0.025% to 0.020%. The treatment in the electric furnace takes 40–50 min. In conclusion the author discusses the mechanical properties of the steel produced, which were very satisfactory.

**The Chromium Reducing Process with Deoxidation by Diffusion in Acid Electric Furnaces—The Zaporozhstal Method.** Yu. Shulte. (Stal, 1939, No. 8. pp. 18–22). (In Russian). The practice and theory of a method of remelting a charge consisting entirely of chromium-nickel or chromium-molybdenum structural steel scrap with not less than 0.25% of carbon and not more than 1.6% of chromium is dealt with. The essential feature of the process after the boil is the diffusional deoxidation of the bath under a special slag consisting of silica and lime (58–65% and 20–25% respectively). The addition of the lime reduces the heavy-metal-oxide content of the slag, and particularly the ferrous oxide content. These are still further reduced by the addition of 3–5% of alumina. Additions of ferro-silicon and carbon are then made to the above slag. The reduction in the free ferrous oxide content of the slag results in an

intense extraction of ferrous oxide from the metal. Diffusion of ferrous oxide into the slag is facilitated by stirring the bath. The final ferrous and chromic oxide contents of the slag are about 2.5% and 1.0% respectively, the amount of slag being 2.0–2.6% of the weight of the charge. Final deoxidation is effected with aluminium. Although some investigators have reported the detrimental effect of aluminium additions on the ductility of chromium-nickel structural steels, the present author points out that this does not occur provided that certain conditions are satisfied. These are essentially: (a) Thorough deoxidation of the steel prior to the addition of the aluminium, which is in fact achieved in the present process as a result of the use of the special deoxidising slag; and (b) the addition of an amount of aluminium slightly in excess of the critical amount necessary just to reduce the ferrous oxide contained in the steel. While it is possible to obtain ductile metal by low-temperature teeming of steel to which no final deoxidising additions have been made, this procedure cannot be recommended for practical application.

**Plural Melting Process.** H. G. Batcheller. (Steel, 1940, vol. 106, Feb. 12, pp. 54–56, 71). Some particulars are given relating to a process of producing ingots of composite steel consisting of stainless or tool steel on one or both sides of a mild-steel base. The process is known as “Pluramelt,” and a special electric-arc furnace is used in which both the mild steel and special steel are brought to a semi-molten condition. No other details of the plant or process are given, but some results of bend, tensile and punching tests on the composite product are discussed.

**Economic Measures for Increasing the Production of the Iron and Steel Industry.** F. Weichselmann. (Stahl und Eisen, 1940, vol. 60, Feb. 29, pp. 169–173). The author gives an account of improvements in the management and control of operations at a small steelworks in Germany comprising open-hearth furnaces, hot- and cold-rolling mills, pickling plant, forge and wire-drawing plant.

**The Formation of Nuclei in Metallic Melts.** L. Horn and G. Masing. (Zeitschrift für Elektrochemie, 1940, vol. 46, Mar., pp. 109–119). After a brief review of present knowledge of the formation of nuclei during the cooling of molten metals, the authors describe their own method of investigation. They used an electric furnace with automatic temperature regulation, and a complicated device with automatic recorders by which cooling curves could be obtained.

## FORGING, STAMPING AND DRAWING

(Continued from pp. 237 A-239 A)

**Forgings for Steam Turbine Rotors.** H. Dahlstrand. (Heat Treating and Forging, 1940, vol. 26, Jan., pp. 9-15). After reproducing some specifications for steel for manufacturing forged turbine rotors which show the progressive increase in the demands made upon the steel producer since 1906 due to the increased pressures and temperatures at which turbines are operated, the author describes the various stages of manufacture of a modern rotor from casting the ingot to inspecting the finished machined and annealed forging.

**The Fundamentals of Plastic Deformation.** F. Körber and A. Eichinger. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1940, vol. 22, No. 5, pp. 57-80). The authors explain the factors necessary for calculating the power required to produce various degrees of plastic deformation, using properties determined from single crystals, and illustrate the application of the calculations with two examples of hot pressings.

**Conditions for the Appearance of Flakes in Chromium-Nickel-Molybdenum Steel Forgings and the Means of Eliminating Them.** I. D. Pichakhehi. (Metallurg, 1939, No. 9, pp. 45-54). (In Russian). Two arc-furnace heats (from which  $3\frac{1}{2}$ -ton ingots were cast) were investigated. The first heat was controlled in such a way as to favour subsequent flake formation (i.e., by incomplete deoxidation by boiling, by deoxidation with ferro-silicon at high temperatures and by the addition of moist lime to introduce hydrogen); while the second one was given a good boil and finished to yield gas-free metal. The ingots were forged down in several stages at 1200-1220° C. After the final forging the samples were cooled in a number of ways, either rapidly by quenching in water, or in air, or after precooling in air, to temperatures of 48-50° C., they were introduced into a furnace at 630° C., and, after holding for various periods, they were cooled in the furnace at different rates and in various stages. Other specimens were placed in the furnace at 630° C. directly after forging without precooling, while another set was allowed to cool down very slowly from the forging temperature. As had been expected, specimens from the first heat had a much larger number of flakes than specimens from the second heat, and also flakes were observed after a larger number of the cooling schedules. Rapid cooling in air from the forging temperature facilitated the differentiation of steel with an inherent tendency to flake formation arising out of incorrect steel-

making practice and steel relatively free from this defect. The choice of a suitable cooling schedule can then be based on this observation. Flakes can best be avoided even in flake-sensitive steel by using a cooling schedule involving an isothermal decomposition of the austenite during which the evolution of hydrogen from the solid solution and its subsequent diffusion take place at elevated temperatures (600–650° C.); the holding time at these temperatures depends on the cross-section of the forgings and the hydrogen content of the steel. An even more favourable result is obtained by supercooling the austenite before subjecting it to heat treatment at the temperature of isothermal decomposition.

**A Brief Résumé of Special Cold Heading Wire Requirements.**

A. M. Reeder. (Wire and Wire Products, 1940, vol. 15, Feb., pp. 99–102, 130). The author discusses the properties of steel suitable for cold-heading and for the exacting requirements of the latest heading practice in which extrusion in the header die takes place simultaneously with the upsetting operation. He describes a drop-testing machine for obtaining data on the plastic properties of steel intended for cold-heading and draws the following general conclusions from data obtained with it: (1) The plastic flow of wire drawn from hot-rolled rods is approximately inversely proportional to its hardness; (2) the "plasticity" of normalised or spheroidised wire appears to be considerably greater than that of the same material of equivalent hardness but not subjected to either of these treatments; and (3) rimmed steel has a greater "plasticity" than killed steel of the same chemical analysis.

**A Correlation of the Factors and Effects of Cold Drawing of Wire Rods.**

S. A. Braley. (Wire and Wire Products, 1940, vol. 15, Jan., pp. 17–29, 77). The author presents a number of tables and graphs relating to the properties of wire at various stages of reduction, and by referring to these data he establishes, where possible, the relationships between chemical composition, tensile strength, reduction in area, hardness and draft.

**Better Wire from Wickwire Brothers.** C. F. Wickwire and J. L. Whitten. (Wire and Wire Products, 1940, vol. 15, Feb., pp. 105–107). The authors describe the annealing equipment recently installed by a New York firm of wire manufacturers. This equipment comprises two 30-in. and two 42-in. dia. vertical, cylindrical, natural-gas-fired furnaces with twelve bases and removable covers for bright-annealing.



## ROLLING-MILL PRACTICE

(Continued from p. 240 A)

**Process Statistics and a Comparison of Rolling-Mill Processes. Part I.—Standardisation of Process Statistics and Division of the Mills and Products into Types of Mill and Capacity Groups. Part II.—The Technical Data for Process Statistics and Process Comparison in the Manufacture of Bars, Shapes, Girders, Wire and Plate.** H. Euler. (Archiv für das Eisenhüttenwesen, 1940, vol. 13, Feb., pp. 359–367; Mar., pp. 409–418). The author discusses and explains the classification of rolling-mill processes and the methods of keeping statistics of rolling-mill operations for costing and control purposes.

**The Influence of Various Lubricants on the Seizure Characteristics of Hard Steel and Bronze.** D. Clayton. (Engineering, 1940, vol. 149, Feb. 9, pp. 131–135). In this report the author, after referring to results obtained previously with typical lubricants in seizure tests in the four-ball apparatus, describes the behaviour of a cutting oil and its emulsion, and related tests with water and no lubricant, using hard steel balls. Results are then given for bronze balls, and for combinations of bronze and steel balls using, first, ordinary lubricants of several types and then the thin liquids petrol and water. In the test referred to, a  $\frac{1}{2}$ -in. dia. steel ball is rotated under load in the cavity between three other similar balls clamped together in a cup containing the lubricant; the speed is 1500 r.p.m., and tests are made at each of a series of loads by measuring the diameter of the impression worn on the three clamped balls.

**Stainless Steel a National Asset.** (Sheet Metal Industries, 1940, vol. 14, Mar., pp. 257–260, 268). An illustrated description is given of a branch works of the United Steel Companies, Ltd., at which billets of stainless steel are hot-rolled, annealed, pickled and then cold-rolled, heat-treated and polished to produce the finished sheets.

**The Relation Between the Advance and the Tension on the End of the Strip Issuing from Between the Rolls.** N. N. Get and K. S. Grigor'eva. (Metallurg, 1939, No. 9, pp. 68–72). (In Russian). In view of the absence of information in the literature on the above subject, experiments were carried out with 99% aluminium, 99.5% copper and lead. Strips of these metals were rolled in a small laboratory mill with the object of (a) relating the advance to the thickness of strip subjected to a given reduction in a number of passes, one strip being rolled with a constant applied tension, while another was rolled without tension; and (b) comparing the advance of strips rolled without applied tension and strips rolled with different applied tension, the reduction in one pass being the same in each

case. The results, which are given in graphical form, show that the application of a tensile stress increases appreciably both the advance and the increase in length of the strips. The latter effect seems to be due to a reduction in the resistance to deformation of the metal, brought about by the applied tension, and is connected with an increase in the reduction in rolling. This increase in reduction in rolling was actually shown to occur. When rolling under tension, a process of drawing the metal through the rolls becomes superimposed on the rolling process proper.

**Mirror Strip with Carbide Rolls.** T. C. Campbell. (Iron Age, 1940, vol. 145, Feb. 1, pp. 44-46). The author describes how a mirror finish is imparted to rolled carbon steel, 18/8 steel and alloy steel strip at the works of the Cold Metal Process Co., Youngstown, by using tungsten carbide rolls. An important feature of the process is the arrangement by which a strip of special-quality paper is wound between the layers of the finished strip on the coiling reels. The finished strip can be produced and wound with paper at speeds up to 2000 ft. per min.

**The Influence of the Conditions of Rolling on the Mechanical Properties, Hardness and Structure of the Metal.** V. P. Severdenko. (Metallurg, 1939, No. 9, pp. 65-67). (In Russian). Some experimental data are presented for 18/8 stainless and low-carbon (0.07%) steel. These indicate that in cold-rolling, the number of passes affects the tensile strength, elongation, hardness and microstructure. For a given total reduction obtained in a large number of passes with small reductions, the tensile strength and hardness are increased, while the elongation is decreased as compared with metal given the same reduction in a fewer number of passes. The greater deformation of the grains results from the larger number of passes with small reductions per pass.

**The Continuous Hot-Straightening of Plates and Hot-Straightening Machines.** P. Pfeffer. (Revue Technique Luxembourgeoise, 1940, vol. 32, Jan.-Feb., pp. 6-11). A French translation is presented of the author's paper on hot-straightening machines which appeared in Stahl und Eisen, 1940, vol. 60, Jan. 18, pp. 48-52. (See p. 188 A).

**Electric Truck Transportation in Sheet and Strip Mills.** C. B. Crockett. (Iron and Steel Engineer, 1940, vol. 17, Feb., pp. 17-23). The author presents and discusses data relating to the selection, performance and operating costs of electric trucks for the transport of coils of strip and packs of sheets in American sheet and strip mills.

## PYROMETRY

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(Continued from p. 143 A)

**Modern Pyrometry.** H. Hirst. (Chemical Engineering and Mining Review, 1939, vol. 32, Oct., pp. 19-23; Nov., pp. 52-54; Dec., pp. 115-119). The author discusses the theoretical and practical aspects of modern pyrometry dealing in turn with thermocouples, electric-resistance pyrometers, and radiation and optical pyrometers.

**Relation of Uniform Pyrometer Records to Uniform Products.** J. A. Doyle. (Heat Treating and Forging, 1939, vol. 25, Dec., pp. 604-608). The author points out many instances where the quality of finished metal products varies considerably, although the recording pyrometer connected to the industrial furnace through which the articles have passed shows that a perfectly uniform temperature has been maintained. He therefore stresses the need of taking into consideration several other factors which influence the process of heat treatment.

**Instrumentation of Continuous Strip Mill at Ebbw Vale.** (Iron and Steel, 1940, vol. 13, Jan., pp. 102-103; Feb., pp. 155-157). An illustrated description is given of some of the systems of temperature measurement and control installed at the continuous strip mill at the Ebbw Vale works of Richard Thomas and Co., Ltd. The instruments employed include two "Optimatic" recording temperature-measuring instruments incorporating photo-electric cells. The optical head is suspended 4 ft. from the strip and is sighted on it, and the temperatures are recorded on a chart at the control panel with a time lag of one-fifth of a second. The instruments for the soaking-pits, pickling tanks, annealing furnaces and tinning machines are also described.

**The Theory and Application of Extended Surface Thermocouples.** H. Emmons. (Journal of the Franklin Institute, 1940, vol. 229, Jan., pp. 29-52). In a mathematical discussion the author considers the problems presented in the measurement of temperatures with thermocouples where one junction has an extended surface, *i.e.*, where the surfaces in contact are sufficiently large for appreciable temperature differences to occur between one part and another.

**The Measurement of Temperature and Flow in Furnace Systems.** A. H. Leckie. (Fuel in Science and Practice, 1940, vol. 19, Jan.-Feb., pp. 20-23). In the course of work for the Open-Hearth Committee of the Iron and Steel Industrial Research Council, the author developed a suction pyrometer and a water-cooled Pitot tube, which enabled him to measure gas temperatures and velocities in furnace passages where temperatures of 1550° C. are attained. He reports

on the results of temperature and flow measurements in open-hearth furnace uptakes. His results indicate that, although waste-gas temperatures in the flues below the checkers may be estimated without serious error by an exposed thermocouple, such a thermocouple will give an entirely erroneous impression of the temperature of the ingoing air.

**Temperature Measurements of Liquid Steel in Basic Open-Hearth Furnaces.** S. Fornander and T. Omberg. (*Jernkontorets Annaler*, 1940, vol. 123, No. 11, pp. 527-544). (In Swedish). The authors describe the construction, calibration and use of two types of thermocouples for determining the temperature of molten steel in a basic open-hearth furnace. One thermocouple was a Fitterer pyrometer with a graphite/silicon-carbide couple; its construction rendered it unsuitable, however, as it was not designed for the type of furnace used for the investigation. The second one was a tungsten-molybdenum couple with a water-cooled sheath so designed that the difference in temperature of the water at the inlet and outlet never exceeded 35° C. in spite of the uninsulated 2½-in.-dia. iron tube forming the jacket. In their discussion of the results obtained with the latter apparatus the authors compare the carbon-content/temperature curves for seven different melts and point out that differences as great as 170° C. at the same carbon content were observed; this may have been due to the small size of the furnace, the capacity of which was about 12 tons. The authors also describe how they fitted a protective sheath of Pythagoras cement which enabled at least six determinations to be made without changing the element. The cost of the element and sheath amounted to 4s. 6d., equivalent to 9d. for each determination. The authors were unable to establish any definite relation between the tapping temperature and the behaviour of the steel in the ingot mould.

**High-Temperature Measurement in a Steel Works.** W. J. Todd. (*Metal Treatment*, 1939, vol. 5, Winter Issue, pp. 171-174, 184). The author discusses various types of optical pyrometers and their limitations. He gives information on the experience gained in the research department of Hadfields, Ltd., when using various types of pyrometers for measuring the temperatures of plain and alloy steels of different compositions, and he refers, in particular, to results obtained with colour pyrometers, describing in detail the technique used in the application of this type of instrument.



## HEAT TREATMENT

(Continued from pp. 241 A-243 A)

**Autogenous Hardening of Cast Iron and Malleable Iron.** G. Kritzler. (*Zeitschrift des Vereines deutscher Ingenieure*, 1940, vol. 84, Mar. 2, pp. 148-150). The author discusses the results of hardness tests on a number of specimens of grey and malleable cast iron, heated in some cases in an electric furnace and in others with an oxy-acetylene flame, and quenched from different temperatures in different media. The experiments show that it is possible to surface-harden blackheart malleable iron with the oxy-acetylene flame to different depths and to produce a structure with any desired hardness in the range 200-600 Brinell.

**Flame-Treating.** J. H. Zimmerman. (*Welding Journal*, 1940, vol. 19, Feb., pp. 104-110). The author describes some more recent applications of the flame-hardening process to special shapes requiring unusual control of contour, as well as to special steels. He also discusses flame-softening and its application to plate edges which have been cut with the oxy-acetylene flame, and, finally, the application of the oxy-acetylene flame for improving the physical properties of parts subject to local regions of stress concentration.

**Heat Treatment of High Carbon Stainless Steel.** D. Swarup and T. V. N. Kidao. (*Quarterly Journal of the Geological, Mining and Metallurgical Society of India*, 1939, vol. 11, Mar., pp. 41-47). The authors describe some experiments in which different forms of heat treatment were applied to specimens of stainless steel containing chromium 14%, carbon 0.65%, manganese 0.65%, tungsten 1.5%, nickel 1.5%, vanadium 1.1% and silicon 0.4%, and the effects on the hardness, microstructure, magnetic properties and corrosion resistance were noted.

**Hack Saw Blades.** R. D. Hawkins. (*Steel*, 1940, vol. 106, Mar. 4, pp. 54-57, 82). The author describes some of the modern machinery and equipment for the mass production of hack-saw blades and screw-drivers at an American plant producing 150,000 of the former and 35,000 of the latter per week. The most interesting features of this plant are the continuous, gas-fired, heat-treatment furnaces with automatic quenching equipment.

**The Heat Treatment of Wire and Wire Products—Electric Bright Annealing.** (*Wire Industry*, 1940, vol. 7, Feb., pp. 71-72). Continuation of a series of articles (*see* p. 242 A). A description is given of some small, electrically heated, continuous and batch furnaces for bright-annealing coils of wire and small pressings.

**Some Problems on Quenched Steels. Part I. On the Cracks of Quenched Steels. Part II. Temper Cracks of Quenched High-Speed Steels.** K. Monma. (Science Reports of the Tôhoku Imperial University, 1939, vol. 28, Oct., pp. 128-142). In the first part of this paper the author reports on an investigation of the causes of cracks which appear on the surface of a quenched high-carbon steel on grinding. He found that such cracks are caused by the shrinkage of the thin surface layer of the specimen due to the transformation from  $\alpha$ - to  $\beta$ -martensite as a result of the heat generated by the grinding process. The formation of such cracks can be prevented by tempering the quenched specimen at about 150° C., so that it will have a  $\beta$ -martensitic structure throughout before grinding. In the second part he examines the causes of the cracks which appear in tempered high-speed steel of the following approximate composition: Tungsten 20%, chromium 5% and cobalt 7%. He explains that these cracks are induced by the tensile stress in the decarburised zone set up by the transformation to martensite of the retained austenite of the inner portion. The formation of cracks can be avoided if the decarburised surface layer is ground off before the tempering operation.

**Grinding Cracks in Quenched Steels.** K. Monma. (Iron Age, 1940, vol. 145, Feb. 29, pp. 44-45). The first part of Monma's paper, entitled "Some Problems on Quenched Steels," is reproduced. (*See preceding abstract*).

## WELDING AND CUTTING

(Continued from pp. 244 A-245 A)

**New Machines for Spot Welding.** W. Brunst. (Elektroschweißung, 1940, vol. 11, Jan., pp. 9-14). The author describes and discusses some recent developments in German spot-welding machines.

**Welding Electrodes and Their Applications.** J. H. Deppeler. (Iron and Steel Engineer, 1940, vol. 17, Feb., pp. 32-46). The author describes and discusses the manufacture of coated welding electrodes, and concludes with a detailed description of the thermit process of welding and its application to the repair of stern frames of ships, large shafts and worn or fractured wobblers on mill rolls.

**Some Observations on Metallic Arc Fluxes.** W. Andrews. (Engineer, 1940, vol. 169, Mar. 8, pp. 224-226). The author discusses and classifies the types of electrode available for the welding of mild steel and considers their characteristics with special reference to the composition of the electrode coating.

**Experience and Results Obtained with the "Vogefa" Method of Examining Electric Welders.** K. Freund. (Elektroschweißung, 1940, vol. 11, Feb., pp. 21-25). The author describes the regulations laid down for testing the skill of electric welders in Germany who are to be employed on the construction of railway trucks. These regulations are known in Germany as "Vogefa" (*Vorschriften für geschweißte Fahrzeuge*).

**Thermit Welding.** W. Aklert. (Stahl und Eisen, 1940, vol. 60, Feb. 29, pp. 173-178). The author discusses the theory and practice of the thermit process of producing pure metals from their oxides and the thermit-welding process. He describes in detail the equipment and technique employed for the thermit-welding of rails and the properties of the joint produced.

**Welding High Sulphur Steels.** J. H. Hruska. (Steel, 1940, vol. 106, Feb. 26, pp. 40-43). The author discusses some of the results obtained in the testing of electrically welded joints in a number of S.A.E. free-cutting steels containing different percentages of sulphur in the range 0.075-0.300%. The results showed that satisfactory welds can be made using welding electrodes high in manganese with a high-amperage current.

**The Production of Pressure Vessels.** (Welding Industry, 1940, vol. 8, Mar., pp. 46-48). An illustrated description is given of the welding department at the works of Daniel Adamson and Co., Ltd., Dukinfield, manufacturers of pressure vessels.

**Study of the Autogenous Welding of Thick Boiler-Plates in the 2-4 Strength Range Using Welding Rods of Various Compositions.** A. Theis and K. L. Zeyen. (Technische Mitteilungen Krupp, Forschungsberichte, 1940, vol. 3, Mar., pp. 49-71; Autogene Metallbearbeitung, 1940, vol. 33, Mar. 1, pp. 57-65). The authors report on an investigation undertaken to determine whether it is possible to produce butt welds by the oxy-acetylene process in thick boiler plate such that the strength of the joint is between 2 and 4 on the German scale of mechanical properties, *i.e.*, with tensile strength between 39 and 44.7 kg. per sq. mm. Eleven different types of welding rods were used and the results showed that the specified strength could be obtained, and even exceeded, using rods containing about 0.87% of nickel with 0.35% of chromium, or 0.27% of molybdenum, or 0.25% of vanadium. It is necessary, however, to normalise the joint.

**Plate-Edge Preparation for Welding.** H. E. Rockefeller. (Welding Journal, 1940, vol. 19, Jan., pp. 5-11). The author describes and illustrates several recently developed improvements to oxy-acetylene cutting machines. These have as their object the acceleration of the cutting speed, the simultaneous cutting of two edges at different angles and the improvement of the rough surface left by the flame, and they thus contribute to the improved quality and lower cost of making electric welded joints. Of particular interest is a "plate-riding device" which enables the distance between the burner nozzle and the surface of the plate to be kept constant when the cutting head is traversing a long sagging plate.

**Fundamental Ideas on the Welding of Various Metals and Common Alloys.** (Revue de la Soudure Autogène, 1940, vol. 32, Jan., pp. 822-832). This article consists of a series of specifications in which recommendations are made in concise form for the oxy-acetylene welding of structural steel; mild, semi-hard and hard steel; copper-bearing and chromium-copper steel; stainless and manganese steel; and a number of non-ferrous metals.

**The Occurrence of Oxides of Nitrogen and Carbon Monoxide in Welding, Cutting and Straightening.** W. Rimarski and M. Kon-schak. (Autogene Metallbearbeitung, 1940, vol. 33, Feb. 1, pp. 29-37; Feb. 15, pp. 43-46). The authors report on an investigation undertaken at the Chemisch-Technische Reichsanstalt, Berlin, with the object of determining to what extent the air in enclosed spaces becomes contaminated with oxides of nitrogen, carbon monoxide and carbon dioxide when using the oxy-acetylene torch for welding, cutting and straightening.

**The Cracking Tendency of Welds Proper with Special Reference to the Chemical Composition of Structural Steel.** E. Helin and S. Svarfesson. (Transactions of the Institute of Welding, 1940, vol. 3, Jan., pp. 14-29). The phenomenon of the cracking of mild-steel welds during cooling has been investigated. The following factors appear to be of major importance: (1) Inclusions of slag



and unfused particles from the electrode coating; and (2) segregating constituents from the weld metal or parent metal. The unavoidable stresses from cooling shrinkage as well as the development of internal gas pressures may be considered primary causes. Such gas pressures may be due to occluded, gassing constituents from the coating or to the development of carbon oxides in the mother-liquor due to excessive concentrations of oxygen, or carbon, or both. Sulphur seems to exert an especially pernicious influence. Carbon and phosphorus *per se* appear to have little effect. In regard to electrodes, many different types meeting various technical demands may be found on the market. While the final development of electrodes has by no means been attained, nevertheless, at the present time there exists hardly any sound commercial structural steel that may not safely be welded. From the viewpoint of general welding development, the major task of the electrode industry appears to be the development of electrodes yielding improved welding economy, together with a constantly tightened control of quality. The present investigation indicates that in regard to the common and economic alloying elements carbon, manganese and silicon, these may be made use of to any extent in the promotion of stronger and better qualities so long as the steel is weldable, *i.e.*, not hardenable to a dangerous extent during normal welding procedure in the cold condition. Moreover it may be inferred that other alloying elements contributing to the attainment of stronger and better structural steels may well be made use of. In regard to phosphorus, as high a content as 0.070% appears to be permissible. With the majority of electrode types sulphur must be considered a potential source of trouble, yet electrode types are to be found which successfully weld highly sulphurous steel plate. In regard to the standardisation of structural steels for welding purposes, it is of primary importance that the steel should not be hardenable. From the viewpoints of cracking and general welding utility and economy, the following divisions may be considered for chemical classification purposes: (1) Rimmed steels containing carbon 0.24% max. and a trace of silicon; (2) killed steels containing carbon 0.19% max. and silicon 0.20% max.; and (3) alloyed structural steels in which the criterion of chemical composition would be that the limit of hardenability is not exceeded. Such a chemical classification complementing the mechanical one generally adopted would result in an increase in efficiency throughout the welding industry.

#### **Some Notes on Structural Steel Intended for Welded Structures.**

H. Herbiet. (*Revue Universelle des Mines*, 1940, vol. 83, Feb., pp. 41-46). After reviewing the changes in the properties of structural steel caused by welding, the author discusses the weldability of high-tensile steel, and of steels containing (a) manganese 0.9-1.5% and copper 0.3-0.6%, (b) nickel 0.5-2.0%, (c) molybdenum 0.20-0.60%, and (d) chromium 0.5-1.5% and phosphorus 0.10-0.20%.

**Welding Metallurgy. Part I. Temperature Changes During Welding. Part II. Types of Steel and their Manufacture.** O. H. Henry and G. E. Claussen. (Welding Journal, 1940, vol. 19, Jan., pp. 55-56; Feb., pp. 134-138). These papers are the first two of a series of lectures prepared by the authors for presentation at the Polytechnic Institute of Brooklyn under the joint auspices of that institute and the American Welding Society. In the first part the authors consider some of the factors causing temperature changes during welding. In the second part they outline the principles of the blast-furnace, the Bessemer converter, basic and acid open-hearth furnaces and electric steel furnaces, and discuss the principal characteristics of different types of steel.

**The Effect of Hydrogen, Arsenic, Titanium and Miscellaneous Elements on the Welding of Steel.** W. Spraragen and G. E. Clausen. (Welding Journal, 1940, vol. 19, Jan., pp. 24-S-30-S). The authors review the literature to July, 1938, on the effect of the presence of the following elements on the welding of steel: Tin, zirconium, antimony, zinc, cobalt, argon, hydrogen, arsenic, titanium, boron, cadmium, lead, selenium, magnesium and silver.

**The Mechanical and Physical Properties of Weld Metal.** W. D. Walcott. (Welding Journal, 1940, vol. 19, Jan., pp. 21-24). The author reports on an investigation undertaken to compare the mechanical properties of the weld metal deposited by the electrodes most frequently used by the manufacturers of welding equipment in Canada.

**Investigation of the Fatigue Strength of Weld Metal and Welded Butt Joints in the As-Welded and Stress-Relieved Conditions.** L. B. Durant and J. F. Ennis. (Welding Journal, 1940, vol. 19, Feb., pp. 61-S-65-S). The authors describe an investigation of the fatigue properties of specimens of weld metal taken from a butt weld made in 1-in. plates by the Unionmelt process (*see* Journ. I. and S.I., 1939, No. I., p. 284 A). The tests showed that the fatigue strength was higher with the metal in the as-welded condition than in the stress-relieved condition, the endurance limits being 35,300 and 30,700 lb. per sq. in. respectively. The endurance limit of the welded joint, as distinct from the weld metal, was found to be 26,400 lb. per sq. in. for both the as-welded and stress-relieved conditions.

**Shear Tests of Plug and Slot Welds.** C. E. Loos and F. H. Dill. (Welding Journal, 1940, vol. 19, Feb., pp. 98-103). The authors describe some shear-strength tests on plug and slot welded joints in  $\frac{1}{4}$ -in.,  $\frac{1}{2}$ -in.,  $\frac{3}{4}$ -in. and 1-in. steel plate. The testing scheme was similar to that of Gibson (*see* Journ. I. and S.I., 1937, No. II., p. 190 A). Four methods of making the holes for the plug welds were used, namely, punching, punching and countersinking, drilling, and oxy-acetylene cutting. The results showed that plug welds made in cylindrical holes with a diameter equal to the plate thickness plus  $\frac{5}{16}$  in. were satisfactory, and that punching was the most economical method of preparing the holes.

## PROPERTIES AND TESTS

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(Continued from pp. 250 A-259 A)

**Flow of Metals.** G. Sachs. (Carnegie Institute of Technology, Symposium on the Cold Working of Metals: Iron Age, 1940, vol. 145, Feb. 1, pp. 34-37; Feb. 8, pp. 36-39). The author summarises and correlates the present knowledge of the plastic flow of metals and discusses in turn the stress-strain relationship, resistance to flow, power consumption in producing flow, the progress of flow in different manufacturing processes and the effects of friction and lubrication.

**Contribution to the Study of the Modulus of Elasticity of Metallic Alloys.** L. Guillet. (Revue de Métallurgie, Mémoires, 1939, vol. 36, Dec., pp. 497-521). The author reports on an investigation of the factors affecting the modulus of elasticity of pure metals and alloys. He describes the Rolland and Sorin apparatus which was used to determine the moduli. His conclusions are as follows: (1) The elastic modulus of a pure metal is related to the atomic volume, the metals with high moduli having a small atomic volume and a high melting point; (2) in solid solutions composed of nearly pure metals the elastic modulus has an almost straight-line relationship to the ratio of the components of the solid solution; (3) inter-metallic compounds fall into two distinct groups, one consisting of those in which the elastic modulus approximately follows the law of mixtures, and the second consisting of those in which the elastic modulus is distinctly higher than that indicated by the law of mixtures; (4) in binary alloys the modulus of elasticity has an almost straight-line relationship to the chemical composition, and it is difficult to raise the modulus of a metal to any appreciable extent by the addition of an alloying element, even if that element has a high modulus; and (5) tempering lowers the elastic modulus of homopolar compounds which undergo allotropic transformation at high temperature; the reduction can be as much as 40%; annealing restores the modulus to its original value.

**A Two-Load Method of Determining the Average True Stress-Strain Curve in Tension.** C. W. MacGregor. (Journal of Applied Mechanics, 1939, vol. 6, Dec., pp. A-156-A-158). The author describes a method, developed at the Massachusetts Institute of Technology, whereby the complete average true stress-strain curve in tension may be determined for a material from the beginning of yielding to fracture, under ordinary testing speeds, by the observation during the test of two values of the changing load applied to a tapered specimen, namely, the maximum load and the load at

fracture. In this method the diameters at various positions along tapered specimens are measured before and after the test, and stress and reduction-of-area values are computed from these observations.

**Contribution on the Impact and Fatigue Strength of High-Duty Grey Cast Iron.** E. Piwowsky. (Giesserei, 1940, vol. 27, Feb. 23, pp. 59-61). The author discusses the impact strength of high-duty grey cast iron and shows that it is not safe to draw conclusions as to the behaviour of the iron under repeated light impacts from the specific impact strength determined from a single fracture-producing impact. He also describes some impact-strength tests made on rings of low-carbon grey iron heat-treated in three different ways. These clearly demonstrated that it is possible by suitable heat treatment to produce a very great improvement in the dynamic properties required to resist ordinary stresses, whilst the improvement in the resistance to single heavy impacts may be very slight.

**The Effect of Capacity for Work Hardening on the Tensile Properties of Austenitic Steel.** J. A. Jones. (Metallurgist, 1940, vol. 13, Feb., pp. 95-99). The author reports on some investigations of the factors affecting the ratio of tensile strength to Brinell hardness of austenitic steel. The results led to the following conclusions: (1) In hot-rolled 18/8 chromium-nickel steel the tensile strength increases as the rate of straining becomes slower, whilst that of 14/12 steel remains constant. (2) In the fully softened condition the tensile strength of both steels is raised as a result of a slower rate of straining, but the effect is more pronounced in the 18/8 steel. (3) Strain-hardening occurs between yielding and break, and it appears reasonable to suppose that this is more effective, the more slowly the strain is applied; the difference in behaviour is thus a probable indication of the relative capacity for strain-hardening of the two steels in the two different conditions, which is also borne out by the relation between the load and area of impression in the Brinell test.

**The Present-Day Possibilities of Photo-Elasticity.** A. Pirard. (Revue Universelle des Mines, 1940, vol. 16, Jan., pp. 1-22). The author describes an apparatus which was designed at Liège University for making photo-elastic stress measurements, and the technique of its operation. He explains how this apparatus can be used, first to determine the amount and position of maximum stress in a body of given shape, and secondly to determine the thickness and shape of a body which will be adequate for the transmission of a given force. He also explains Föppl's calculations for the separate determination of the principal stresses.

**A Simplified Process for the Determination by X-Rays of the Amount and Direction of the Principal Stresses.** F. Stäblein. (Materials Committee of the Lilienthal Gesellschaft, June, 1939: Technische Mitteilungen Krupp, Forschungsberichte, 1939, Anhang, pp. 29-33). The author refers to the X-ray technique developed and improved by Glocker, Osswald and Gisen for the measurement of internal stresses in steels, and he now describes a further improve-



ment of the technique developed in the Krupp Testing Laboratories. The method described in this paper permits the lattice constant in the stress-free state and the amount and direction of the principal stresses to be determined from two back-reflection diagrams taken obliquely, with an accuracy equal to that with which one of these factors was determined from one radiograph by the earlier methods.

**Interesting Examples of Internal Stresses.** F. Stäblein. (Materials Committee of the Lilienthal Gesellschaft, June, 1939 : Technische Mitteilungen Krupp, Forschungsberichte, 1939, Anhang, pp. 33-34). The author gives some examples of the application of an improved X-ray method of determining stresses (*see* preceding abstract), and compares the results with those obtained using a tensometer. The examples include the measurement of stress in : (1) A steel plate with a groove in which weld metal had been deposited by the electric-arc process ; (2) a bent steel specimen ; and (3) a steel plate in which a bullet is embedded.

**The Applicability of X-Ray Back-Reflection Interference Lines for Stress Measurements in Alloyed, Tempered and Hardened Steels.** F. Gisen. (Materials Committee of the Lilienthal Gesellschaft, June, 1939 : Technische Mitteilungen Krupp, Forschungsberichte, 1939, Anhang, pp. 35-40). The author reports on a number of X-ray investigations which were undertaken with the object of determining whether the back-reflection technique would produce sufficiently sharp interference lines for accurate stress determinations when applied to different alloy steels heat-treated in various ways. The results showed that : (1) Only when in the tempered state was it possible to measure elastic stresses in nickel-chromium-molybdenum steel using cobalt radiation ; and (2) the alloy steels which gave either diffused interference lines, or none at all, with cobalt radiation, gave very much sharper lines with chromium radiation.

**Surface Pressing.** O. Föppl. (Metallwirtschaft, 1940, vol. 19, Mar. 1, pp. 162-164 ; Mar. 8, pp. 182-185). The author discusses the physical aspect of the composition of metals with particular reference to the occurrence of minute surface discontinuities which form the starting-points of fatigue cracks. He then describes the process of surface pressing which can be applied to cylindrical surfaces and to screw threads. In this process a roller with a rim half-round in section is moved over the surface of the material with sufficient pressure to cause slight plastic deformation, and it thus closes up the minute cracks. The author gives some examples of the surface pressing of steel close to keyways and where changes of section occur which have resulted in greatly increasing the fatigue strength of the material.

**The Fatigue Endurance of Killed, Capped and Rimmed Steels.** J. F. McDowell. (Metals and Alloys, 1940, vol. 11, Jan., pp. 27-32). The author describes an investigation of the comparative fatigue strengths of specimens of killed, capped (semi-killed) and rimming

steels of approximately the same composition (carbon 0.20–0.25%) and with similar physical properties. The steels differed considerably in their ability to withstand repeated stress reversals, the killed steel withstanding the largest number and the rimming steel the lowest number. Additional tests with decarburised and non-decarburised killed steel showed that the former had a much lower fatigue resistance.

**The Damping Capacity of Steel and its Measurement.** G. P. Contractor and F. C. Thompson. (Iron and Steel Institute, 1940, see this Journal, Section I.). The Föppl-Pertz apparatus for the measurement of the damping capacity of steel was found to yield unduly high values, mainly as the result of frictional losses between the stylus and the recording medium. To eliminate these, the instrument was modified so as to employ an optical recording device. Particular attention has been paid to a consideration of the effect on damping capacity of factors such as the initial stress, bending, size and shape of the specimen, &c. An account is given of experiments to study the influence of moderate temperatures on the damping capacity of a series of typical steels. This work, which is of an exploratory nature, covers only an account of the experimental results and no attempt is made to deal with them theoretically.

**The Life of Helical Springs With and Without Surface Defects.** A. Pomp and M. Hempel. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1940, vol. 22, No. 4, pp. 35–56). From a review of the literature on the testing of helical valve springs the authors show that there is no published information on the behaviour of valve springs in fatigue tests at above 10 million reversals, nor has anyone studied the effect of surface defects on their life. They therefore undertook an investigation of these points, a detailed report of which is here presented. The testing machine was designed to test twelve springs simultaneously, and it was fitted with an electric device by which the fracture of any one spring was signalled by a lamp. The machine was also connected to oscillographs which recorded the movements of each coil of each spring. The springs tested were made of 3.6-mm. dia. wire of tempered steel containing carbon 0.67%, silicon 0.20%, manganese 0.59%, phosphorus 0.016% and sulphur 0.019%. They were 62 mm. long and were made up of eight coils about 32 mm. in dia. The “defective” springs tested had notches cut in them, some on the inside and some on the outside of the coils; in other cases the springs were subjected to local overheating. An analysis of the results obtained showed that of 183 springs tested, 71 broke; of these, 34% failed at under 10 million reversals and 66% at between 10 and 50 million reversals. Out of the total of 183 springs, 133 had artificial defects, and at under 10 million reversals only 5 broke at the defect and 19 broke at other places; whilst at between 10 and 50 million reversals, 27 broke at the defect and 20 at sound parts of the wire. It was observed that longitudinal shallow scratches (0.03 mm. deep) on the outside of the coils

and local heating of a coil up to 300° C. had no appreciable effect on the life of the spring. The depth of notches cut on the inside of the coils and transverse to the axis of the wire had a very marked effect on the life of the spring, although the fracture occurred in most cases away from the notch. Macrographs of the fractures showed that these were of two kinds, *viz.*, the fracture was in one plane if it emanated from an internal defect, and in two planes when caused by a surface defect. The springs were also tested by the magnetic powder method, and it was found that the powder heaped up in a line parallel with the axis of the wire in the case of the undamaged springs, a phenomenon probably due to magnetic irregularities in the material. The authors were unable to establish any relation between the magnetic properties and the incidence of fatigue failures.

**D.P.H. Measurements With Rockwell Hardness Test.** J. H. Hruska. (Iron Age, 1940, vol. 145, Feb. 1, pp. 29-33). In order to combine the advantage of the rapidity of manipulation of the Rockwell hardness tester with the accuracy and wide range of the diamond-pyramid instrument, the author substituted a 136° diamond-pyramid indenter for the ball in a Rockwell machine. In this paper he gives tables and graphs showing the results of a large number of hardness tests with the ball and the pyramid under loads of 60 kg., 100 kg. and 150 kg. These demonstrated the utility of the combination of processes, as he obtained a straight-line relationship in each case between the Rockwell C numbers and the diamond-pyramid hardness units.

**Pendulum Method of Measuring Hardness.** S. R. Williams. (Instruments, 1939, vol. 12, Sept., pp. 257-262, 264). The author describes the Herbert pendulum hardness-testing instrument, its principles and method of operation.

**Pendulum and "Cloudburst" Methods of Measuring and Testing Hardness.** S. R. Williams. (Instruments, 1939, vol. 12, Nov., pp. 301-303). The author describes Rehbinder's modification of the Kusnezow pendulum hardness tester and Herbert's "Cloudburst" hardness tester and some of their applications.

**A Micro-Hardness Tester.** H. Hanemann and E. O. Bernhardt. (Zeitschrift für Metallkunde, 1940, vol. 32, Feb., pp. 35-38). The authors describe a hardness-testing instrument which is a development of that of Lips. With the Lips instrument there are three stages of the process, namely, the selection of the spot to be tested, production of the impression and measurement of the impression. Of these, the second is a mechanical operation and the other two are optical, and the instrument therefore incorporates a mechanical device for moving the specimen. In the instrument here described the diamond is mounted on the front lens of the objective and the selection of the spot for the impression can be made with an accuracy of 10-50 microns, according to the type of machine.

**A Note on the Permalloy Problem.** H. Schlechtweg. (Technische Mitteilungen Krupp, Forschungsberichte, 1940, vol. 3, Mar., pp. 73-



74). The author develops a new theory in order to explain the relation between the magnetic permeability of Permalloy and the state of atomic disorder of this alloy.

**On the Effect of a Special Heat Treatment on the Magnetic Permeability of Nickel-Iron Alloys.** T. Nishina. (Science Reports of the Tôhoku Imperial University, 1939, vol. 28, Oct., pp. 225-232). The author reports on some tests on six different nickel-iron alloy wires containing from 50% to 90% of nickel, which were subjected to special heat treatment under tension with subsequent measurement of their magnetic properties. The results showed that the maximum permeability of alloys having a positive magnetostriction first increased with increasing applied tension, but after reaching a maximum the permeability decreased gradually. The opposite effect was observed with the alloys with a negative magnetostriction.

**Magnetic Method of Sorting Rolled Steels of Different Compositions.** V. P. Spivak and P. E. Dolbonosov. (Zavodskaya Laboratoriya, 1939, No. 6, pp. 592-595). (In Russian). A simple apparatus operating on the differential magnetic principle for classifying rolled steels is described. In the case of normalised or annealed steel the sorting is based on the straight-line relation between the carbon content and the coercive force. Manganese and silicon in the amounts usually present have little effect. The method is only applicable to cold-rolled steels with a carbon content of 0.3% to 0.5%, as above that value the coercive force no longer varies with the carbon content.

**Steels for Electrical Purposes.** E. Marks. (Sheet Metal Industries, 1940, vol. 14, Mar., pp. 265-268). The author discusses the electrical and magnetic properties of silicon-steel sheets and their application in the construction of transformers and motors.

**The Exact Measurement of the Specific Heats of Solid Substances at High Temperatures. XII. The Specific Heats of Iron-Nickel Alloys of Various Compositions between 100° and 1400° C.** A. J. Zuithoff. (Receuil des Travaux Chimiques des Pays-Bas, 1940, vol. 59, Feb., pp. 131-160). The author presents the results of determinations of the specific heat of iron-nickel alloys with about 10%, 20%, 30%, 40%, 50%, 70% and 80% of nickel carried out at the Laboratory for Inorganic and Physical Chemistry of the Groningen University. The heat content and the specific heat showed a minimum value at about 30% of nickel, which fact is in agreement with the occurrence of a minimum thermal expansion in the case of the alloy Invar containing 35% of nickel.

**Testing Steels for Brittleness at High Temperatures.** E. Siebel and K. Wellinger. (Archiv für das Eisenhüttenwesen, 1940, vol. 13, Mar., pp. 387-392). The authors state that the limiting creep stress of a steel as determined by the German standard method does not always present a true picture of the behaviour of the steel at high temperatures, and that the steel should also be tested for brittleness. In this connection they report on some tests made with



chromium-nickel-molybdenum steel bolts which showed that embrittlement is associated with a reduction in the notched-bar impact strength and an increase in the hardness, tensile strength and elastic limit. The tests with this steel included heating it under load, and it was found that it did not become brittle until a temperature of  $470^{\circ}\text{C}$ . was reached. The embrittlement increased with increasing load, but the authors also observed that embrittlement occurred in a comparatively short time under a load much less than that specified in the German standard method of determining the limiting creep stress. Additional tests with smooth and notched specimens of this steel held under load at  $500^{\circ}\text{C}$ . until fracture took place demonstrated its tendency to fracture in a comparatively short time.

**Report of Short Time Creep Tests on Arc Welded Low Carbon Steel.** N. F. Ward. (Welding Journal, 1940, vol. 19, Jan., pp. 14-S-20-S). The author reports on a series of creep tests which were undertaken to compare the creep at temperatures of  $500^{\circ}$ ,  $700^{\circ}$  and  $900^{\circ}\text{F}$ . of unwelded and welded specimens of 0.10% carbon steel prepared in four different ways: (a) Cold-drawn; (b) cold-drawn and annealed; (c) cold-drawn and welded with a coated electrode using alternating current; (d) cold-drawn, welded and annealed.

**Creep at High Temperatures.** H. J. Tapsell. (Engineering, 1940, vol. 149, Mar. 15, pp. 287-288). An abridged version of the author's paper on the creep characteristics of metals with special reference to the behaviour of carbon and molybdenum steels is presented (*see* p. 253 A).

**Method of Determining the Limiting Deformation and the Limiting Stress in Creep.** I. A. Oding. (Zavodskaya Laboratoriya, 1939, No. 8, pp. 856-859). (In Russian). Limiting deformation is defined as the deformation undergone by a specimen up to the commencement of necking, which sets in when the intensity of work-hardening becomes equal to the loss in strength as a result of the reduction in cross-sectional area. Both the limiting deformation and the limiting stress can be obtained graphically from the stress-elongation diagram, and this enables the approximate life of the material for a given stress and creep rate to be determined, provided that the material does not undergo structural changes at the temperatures involved.

**The Mathematical Treatment of Creep Curves.** A. Eichinger. (Archiv für das Eisenhüttenwesen, 1940, vol. 13, Mar., pp. 397-402). In this mathematical discussion the author deals with the characteristics of stress-elongation, time-elongation and time-stress curves plotted from data obtained in creep tests, and the application of these curves in the estimation of the behaviour of steel at high temperature in industrial practice.

**Reducing Creep in Alloy Steel Bolting Materials.** J. J. Kanter. (Steel, 1940, vol. 106, Mar. 4, pp. 44-48, 72). In order to simulate the stresses to which pipe-flange bolts are subjected in service, a

creep-testing apparatus has been devised with which the rate of creep of steel bars can be determined under diminishing loads. In this paper the author discusses the results of creep tests made with such an apparatus using a number of low-alloy steels to the A.S.T.M. specifications for steel for bolts.

**The Diffusion of Hydrogen in Iron.** (Metallurgist, 1940, vol. 13, Feb., pp. 89-90). A discussion is presented of the results obtained by Güntherschulze and Betz in their experiments relating to the diffusion of hydrogen in iron at different temperatures. These investigators determined diffusion constants  $D$  in sq. cm. per day at temperatures from  $-50^{\circ}\text{C.}$  to  $+300^{\circ}\text{C.}$ , and these could be expressed by the linear equation

$$\log D = 0.0193T - 5.66$$

where  $T$  is the absolute temperature. It is shown why these results were not expected to correspond with those determined by Smithells and Ransley and by Borelius and Lindholm.

**The Solubility of Nitrogen in Steel.** L. Eklund. (Jernkontorets Annaler, 1940, vol. 123, No. 11, pp. 545-555). (In Swedish). The author describes an investigation which had as its objects: (1) The determination of the solubility of nitrogen in low-carbon steel (under 0.04%); and (2) the relation between the nitrogen solubility and the temperature, carbon content and amount of aluminium added to kill the steel. The apparatus used consisted of an H.F. furnace fitted for melting steel under nitrogen, and a device which enabled samples to be removed and analysed without contact with the air. The results indicate that the nitrogen solubility varies slightly with the temperature, the rate of solution being higher at higher temperatures. A curve showing the relation between the carbon and nitrogen contents at about  $1550^{\circ}\text{C.}$  demonstrates that the nitrogen decreases rapidly as the carbon increases. The amount of aluminium used had little effect upon the nitrogen solubility.

**Progress in Metallurgical Application of Titanium in 1939.** G. F. Comstock. (Blast Furnace and Steel Plant, 1940, vol. 28, Jan., pp. 45-46). The author reviews the extensions in the use of titanium which have taken place in America during 1939. It has been used in conjunction with deoxidisers such as aluminium, silicon and vanadium to improve the physical properties of heat-treated forgings of pearlitic manganese steels. Ferro-carbon-titanium has been successfully employed to improve the rimming action of effervescing steels, and the same compound, when added in such small quantities as 1 or 2 lb. per ton of steel, lessens the cracking tendency of rails.

**Copper in Cast Iron.** T. Barlow. (Iron Age, 1940, vol. 145, Jan. 25, pp. 19-22; Feb. 1, pp. 40-43, 77; Foundry Trade Journal, 1940, vol. 62, Mar. 7, pp. 181-182; Mar. 14, pp. 203-204). The author discusses several practical examples of the effects of additions of up to 2.25% of copper to cast iron, the principal effects being

to control the depth of chill, obtain increased wear resistance and maintain or improve the machinability. He describes and illustrates some examples of castings made with copper-bearing iron and makes recommendations as to the correct technique for making the copper additions.

**The Effect on Cast Iron of Vanadium Additions to the Ladle.** J. Wisser. (Giesserei, 1940, vol. 27, Mar. 8, pp. 81-83). The author reports the results of tests on the mechanical properties, shrinkage and fluidity of six different qualities of cast iron to which ladle additions of vanadium were made. The analyses of the irons tested were within the following limits: carbon 2.79-3.37%, silicon 1.42-2.43%, manganese 0.29-0.80%, phosphorus 0.16-0.53% and sulphur 0.069-0.131% and the amount of vanadium added varied between 0.12% and 0.42%.

**Chromium-Silicon Cast Iron.** A. L. Norbury and E. Morgan. (British Cast Iron Research Association, Report No. 93: Foundry Trade Journal, 1940, vol. 62, Feb. 15, pp. 137-141). This paper contains a survey of the microstructures, tendency to chill, mechanical properties (such as Brinell hardness, machinability, tensile strength, transverse strength, deflection and repeated impact values) and air- and oil-hardening capacities of cast irons having chromium contents between 0% and 15% and silicon contents between 1% and 11%. The conclusions from the results may be summarised as follows: (1) 1% of 69% ferro-chromium added to crucible melts increased the chromium content of the resulting cast on an average by 0.6%. (2) Increasing the chromium content stabilised the pearlite and secondary cementite and caused white-iron eutectic to replace graphite, but did not cause self-hardening or the replacement of pearlite by martensite. (3) In cast irons of normal total-carbon content, the chill-producing action of 1% of chromium neutralised the chill-reducing action of about 1% of silicon. (4) Chromium increased the Brinell hardness and reduced the machinability. In most compositions it increased the mechanical strength and reduced the deflection. (5) As the chromium content increased, the white-iron eutectic assumed the form of carbide crystals in a ferrite matrix, instead of austenite globules in a carbide matrix. (6) Experiments not included in this paper showed that chromium raised the freezing point of the white-iron eutectic.

**Vanadium in Cast Iron and Cast Steel.** F. Stadler. (Giesserei, 1940, vol. 27, Feb. 23, pp. 57-59). The author discusses the sources of supply and consumption of vanadium in Germany and describes the improvements in the properties of cast iron and cast steel which are obtained by additions of up to 0.20% of this metal.

**Types of Stainless Steel Manufactured in Germany Pending Shortage of Nickel.** H. Hougardy. (Wire and Wire Products, 1940, vol. 15, Feb., pp. 103-104). The author presents data relating to the analyses and properties of the chromium, chromium-molybdenum, chromium-silicon and chromium-manganese steels

now manufactured in Germany as substitutes for steels containing nickel.

**Stainless Steel Rolled Products.** P. B. Greenawald. (Electrochemical Society, 1940, Apr., Preprint No. 15). The author reviews the development in the production of stainless steel during the last twenty years. He deals in particular with improvements due to variations in the composition and to special heat treatment, which made possible the production of stainless steels as workable as ordinary carbon steels. Special mention is also made of free-cutting stainless steels containing small percentages of sulphur or selenium. Finally the author discusses a number of American standard stainless steels, giving their compositions and specific properties and uses.

**Properties, Heat Treatment and Finishing of Stainless Steels.** E. F. Ingersoll. (Metal Industry, New York, 1940, vol. 37, Nov., pp. 503-506). The author reviews the composition and properties of a number of stainless steels and describes the processes of pickling, welding, soldering, deep-drawing, spinning and polishing this class of steel.

**High-Tensile Structural Steels Containing Copper.** (Metallurgist, 1940, vol. 13, Feb., pp. 93-95). The work of several German investigators on the effect of additions of copper on the mechanical properties of high-tensile structural steel is reviewed, and many of the results obtained by Houdremont, Bennek and Neumeister on the effects of copper in manganese and in manganese-chromium steels are presented. (See Journ. I. and S. I., 1939, No. II., p. 294 A).

**Sling Chains.** H. A. Delano. (Steel, 1940, vol. 106, Feb. 19, pp. 54-56, 80). The author describes the mechanical properties of three types of sling chains manufactured by an American firm. These are made from: (a) Hot-rolled steel, normalised, with a tensile strength of 55,000 lb. per sq. in., (b) carbon steel to a controlled analysis, normalised, with a tensile strength of 85,000 lb. per sq. in., and (c)  $3\frac{1}{2}\%$  nickel steel with a tensile strength of 125,000 lb. per sq. in. when normalised, heat-treated and drawn. All links in these chains are welded at the end. These three types of steel are known as Endweldur 55, 85 and 125 respectively.

**Discussion of the New Law of Design of Cast-Iron Pipe.** W. D. Moore. (Journal of the American Water Works Association, 1939, vol. 31, Oct., pp. 1655-1670). One of the American Standards Association's sectional committees was set up in 1926 to prepare new standard specifications for cast-iron pipes and fittings. After thirteen years of intensive work the committee has developed a new method of calculating thicknesses of cast iron and has prepared a detailed specification for vertically cast pipe, the thickness of the pipe wall being calculated in accordance with the new design principle. In the present paper the author discusses the work of the above committee and explains the new design and method of calculation.



## METALLOGRAPHY AND CONSTITUTION

(Continued from pp. 260 A-264 A)

**Standardisation of the Evaluation of the Depth of the Decarburised Surface Layer in Steel.** I. N. Golikov and M. I. Vinograd. (Zavodskaya Laboratoriya, 1939, No. 7, pp. 713-715). (In Russian). Conditions are laid down for the preparation of sections and for the microscopic measurement of the depth of decarburisation of both the completely and the partially decarburised zones of steel specimens. The method is applicable to all carbon and alloy steels, but not to steels of the ledeburitic class.

**The Economic Aspects of Non-Destructive Material Testing.** E. A. W. Müller. (Stahl und Eisen, 1940, vol. 60, Mar. 14, pp. 221-226). The author discusses the increase in cost of production and the value of the information obtained when materials are tested by X-rays and by the magnetic powder method. He describes the X-ray testing of welded steel bridges, locomotive fireboxes, boilers and castings of various sizes which are produced in large quantities, as well as the magnetic powder testing of machinery parts. From an analysis of the costs of testing in the examples quoted he shows that this item is not an unreasonable proportion of the total cost of the product. In conclusion he describes some recent improvements to the testing apparatus.

**Industrial Radiography.** R. G. Tobey. (Iron Age, 1940, vol. 145, Feb. 29, pp. 27-30; Mar. 7, pp. 64-67). In the first part of this article the author illustrates some 220-kV. and 400-kV. X-ray apparatus as supplied for industrial purposes and describes in non-technical terms the principles employed. In the second part the author describes some industrial applications of soft X-ray technique requiring only 4-5 kV. and gives some information relating to recent improvements in equipment, as, for example, flexible calcium-tungstate intensifying screens which can be used in a curved or flexible cassette, a new type of direct-exposure X-ray film intended for use when fluorescent intensifying screens are unnecessary or unsatisfactory, and developing solutions which decrease the developing time. In conclusion he discusses some of Moriarty's work with stereoscopic X-ray technique.

**The Use of X-Rays in Inspection Methods.** G. E. Bell. (Journal of the Institution of Production Engineers, 1940, vol. 19, Feb., pp. 39-58). The author discusses the uses and limitations of radiographic examinations in engineering practice. The production and properties of X-rays, in so far as these have a bearing on radiographic technique, are briefly outlined, and the factors influencing the

fineness of resolution of radiographs are considered as well as the precautions necessary to ensure that the maximum possible resolution is obtained. The radiographic appearances of the defects most commonly encountered are exemplified by means of some typical radiographs, mainly of castings and welds, and the conditions affecting the ability to discern blow-holes, pipe and cracks are discussed.

**The Use in Metallographic Research of Patterns Obtained with Monochromatic X-Rays.** A Guinier. (*Métaux et Corrosion*, 1939, vol. 14, Dec., pp. 151-155). The author points out that the X-rays used for ordinary Debye-Scherrer patterns are not strictly monochromatic, and he suggests the insertion of a "monochromator" between the X-ray tube and the diffraction chamber. The monochromator he used consisted of a quartz lamella which, at a given angle, reflected one wave-length only. Its application, when mounted in the manner described by the author, caused increased clarity and precision of the patterns without necessitating prolonged times of exposure.

**Notes Regarding Spectrographic and X-Ray Tests of Metals Used in Modern Industrial Welding Practice.** W. H. Cohn. (*Welding Journal*, 1940, vol. 19, Feb., pp. 138-141). A brief explanation is given of the principles involved in the examination of welds by spectrographic and X-ray tests.

**Methods for the Preparation of Metal Single Crystals.** L. Guillet, jun. (*Chimie et Industrie*, 1940, vol. 43, Feb. 20, pp. 283-286). The author reviews the most important methods by which metal single crystals can be obtained from the gaseous, from the liquid and by recrystallisation, from the solid state. Finally he briefly describes the preparation of single crystals by electrolysis.

**The Metallurgical Importance of Single Crystals. Their Production and Their Use in the Study of Deformation Phenomena.** L. Guillet, jun. (*Revue Générale des Sciences*, 1939, vol. 50, Dec. 31, pp. 424-432). The first part of this paper, in which the preparation of single crystals is described, is an abridged form of the paper published by the author in *Chimie et Industrie* (see preceding abstract). In the second part of the paper the author briefly reviews the present knowledge on the deformation of single crystals, dealing separately with elastic and plastic deformation, and, under the latter heading, considering slip and twinning. In conclusion he discusses the possibilities of transferring the results obtained for single crystals to technical polycrystalline materials.

**Researches into the Structure of Alloys.** A. J. Bradley, W. L. Bragg and C. Sykes. (*Iron and Steel Institute*, 1940, see this Journal, Section I.). The paper describes a body of related researches which have been carried out in the last few years. Part I. deals with the investigation of equilibrium diagrams by means of X-ray analysis, in particular the analysis of binary and ternary diagrams with the component metals chromium, iron, cobalt, nickel, copper and alum-

inium. Structures of submicroscopic order of magnitude and the theory of the order-disorder transformation are also reviewed. Part II. deals with the experimental investigation of the order-disorder transformation, using the alloys of  $\beta$ -brass,  $\text{Cu}_3\text{Au}$ ,  $\text{Cu}_3\text{Pd}$  and  $\text{Ni}_3\text{Fe}$ . The values found for the energy of the transformation are in satisfactory agreement with those predicted by the theoretical treatments given by Bragg and Williams, Bethe and Peierls. The thermal methods specially developed for the above investigation have also been employed to determine the specific-heat/temperature curves of iron, nickel and a number of age-hardening alloys. The results obtained from consideration of these curves are recorded.

**Some Observations on the Recrystallization of an Iron-Nickel Alloy.** G. Sachs and J. Spretnak. (American Institute of Mining and Metallurgical Engineers, Technical Publication No. 1143: Metals Technology, 1940, vol. 7, Jan.). In studies of recrystallisation it had been found that in steel the orientation of the crystals obtained after annealing was of an entirely different type from that observed in rolled unannealed steel. The present authors report the results of an X-ray investigation of the structure of an austenitic iron-nickel alloy sheet, containing 36% of nickel, which they undertook in order to obtain more information on the above phenomenon. Three conditions of the alloy were studied: (1) Cold-rolled with 95% reduction; (2) as in (1) but annealed for 30 min. at  $900^\circ\text{C}$ .; and (3) as in (2) with an additional reduction of 10% after annealing. The authors conclude that the process of recrystallisation in this particular case was consistent with the theory that the process is initiated by some specially orientated fragments of the deformed metal. These fragments, for some reason still unknown, are more favoured to form nuclei, to grow on recrystallisation, and to survive on grain growth, than is the remainder of the metal.

**The Use of the Electric-Resistance Method for Studying the Isothermal Transformation of Austenite.** L. S. Lavrent'ev. (Zavodskaya Laboratoriya, 1939, No. 8, pp. 879-882). (In Russian). Some details of an electrical apparatus for studying the isothermal transformation of austenite are described. In order to be able to deal with steels in which the decomposition of the austenite starts immediately after quenching, an apparatus was set up which comprised a vertical electric furnace, quenching chamber and thermostat. The specimens (70 mm. long, 3 mm. in dia.) were heated by passing an electric current through them, supercooled by a blast of compressed nitrogen and then moved into the thermostat, where the transformation proceeded at the required temperature. The changes in resistance were determined from galvanometer readings or could be recorded automatically. Some results obtained by this method are given and discussed. While the method is not as sensitive as the magnetic method, the sensitivity varying with temperature, it can be used without hesitation for determining the upper range of minimum stability of the austenite in oil-quenching steels.

**The Alpha-Gamma Transformation of Iron at High Pressures and the Problem of the Earth's Magnetism.** F. Birch. (American Journal of Science, 1940, vol. 238, Mar., pp. 192-208). The author describes a dilatometer apparatus with which he was able to determine the temperatures at which the  $\alpha \rightarrow \gamma$  transformation took place in high-purity iron in nitrogen and in argon at different pressures up to 4000 kg. per sq. cm. From the results obtained he deduces by calculation that the transformation temperature decreases with increasing pressure, above 1000 kg. per sq. cm., at the rate of  $8.5^\circ \text{C.}$  for every 1000 kg. per sq. cm. increase in pressure. From this rate and the change in volume he calculates the latent heat of the iron to be about 4 cal. per g. In conclusion he discusses the significance of these findings in relation to the problem of the earth's magnetism.

**Hardenability of Molybdenum S.A.E. Steels.** R. M. Parke and A. J. Herzig. (Metals and Alloys, 1940, vol. 11, Jan., pp. 6-13). The authors report on an investigation of the hardenability of eight molybdenum-bearing S.A.E. steels, one manganese-molybdenum-silicon steel and one carbon steel. The isothermal transformation or S-curves were plotted, and, in addition, the decomposition of the austenite between  $650^\circ$  and  $400^\circ \text{F.}$  was studied dilatometrically, using a special apparatus which is described in detail. An examination of the time-dilatation curves at  $500^\circ \text{F.}$  for the manganese-molybdenum-silicon steel leads to the belief that separate reactions take place, the first beginning in less than 1 sec. and ending in 5 sec., the second beginning in 35 sec. and ending in about 120,000 sec. The curve at  $450^\circ \text{F.}$  shows that the first reaction ends sooner and the second reaction begins and ends later; at  $400^\circ \text{F.}$  this trend continues. A cinema-camera making 64 exposures per sec. was used to obtain more detailed data concerning the first reaction. Observations with this on one of the molybdenum steels at  $600^\circ \text{F.}$  showed that the contraction on cooling changed to expansion within about 0.1 sec. and that the reaction was substantially complete in 2 sec. At  $450^\circ \text{F.}$  the same steel began to transform in  $\frac{1}{32}$  sec. after it stopped contracting, and the first reaction was complete within 1 sec. The authors' general conclusions from the observations made were: (1) The shapes of the S-curves for alloy steels are different from those for carbon steels; (2) the effect of the alloying elements in reducing the critical quenching rate was clearly indicated by the shifting of the nose of the curve to the right (*i.e.*, longer time); (3) the effect of the alloying elements on the lower part of the S-curve was relatively small and greatly overshadowed by the effect of carbon; (4) the fact that increasing the carbon content extended the region of austenite stability below  $900^\circ \text{F.}$  afforded an explanation of the varied response of low-, medium- and high-carbon steels to hardening; and (5) the results of the investigation direct attention to the possibility of selecting steels with additions of alloying elements



so adjusted that the critical cooling rate is suitable for the section of the steel and with a carbon content that will enforce transformation to an acicular product of the desired hardness when heat treated and tempered in the conventional manner.

**One or Two Vanadium Carbides in Steel?** E. Maurer, T. Döring and W. Pulewka. (Archiv für das Eisenhüttenwesen, 1940, vol. 13, Feb., pp. 337-344). By quantitative determinations of the carbide associations in seven different vanadium steels the authors found that there were two vanadium carbides present with the composition VC and  $V_4C_3$ . In order to check this, some synthetic carbides of these two compositions were prepared, and both these and the natural carbides were examined by X-rays. All the specimens revealed the same cubic face-centred lattice with a length of side, calculated by Bragg's equation, equal to  $4.152 \text{ \AA}$ . within  $\pm 0.005 \text{ \AA}$ . These chemical and radiographic determinations were in agreement with Hägg's findings.

**The Iron-Silicon-Vanadium Constitutional Diagram.** R. Vogel and Charlotte Jentzsch-USchinski. (Archiv für das Eisenhüttenwesen, 1940, vol. 13, Mar., pp. 403-408). The authors construct the complete iron-silicon-vanadium constitutional diagram from the diagram of the Fe-FeSi-VSi<sub>2</sub>-V portion of the system and from the results of thermal, microscopic and X-ray investigations.

## CORROSION OF IRON AND STEEL

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(Continued from pp. 265 A-267 A)

**Combined Mist and Rain Chamber of the Rotary Type for Corrosion Tests.** A. S. Afanas'ev. (Zavodskaya Laboratoriya, 1939, No. 8, pp. 872-873). (In Russian). Constructional details of a chamber for carrying out corrosion tests are described and illustrated. The specimens, which are carried on a horizontal rotating disc situated near the bottom of the chamber, can be exposed to artificial rain falling on them from 200  $\frac{1}{2}$ -mm. dia. holes in a battery of 8-mm. dia. tubes, or to mist. The latter is produced by a set of atomising nozzles situated below the rotating disc in order to prevent direct impingement of droplets on the specimens. In the absence of this artificial mist or rain, the humidity in the chamber is controlled. Reproducible results were obtained in tests on carbon-steel specimens.

**Protection of Iron and Steel against Corrosion.** J. C. Hudson. (Iron and Steel, 1940, vol. 13, Jan., pp. 111-113; Feb., pp. 158-159). The author discusses some of the recommendations of the Protective Coatings Sub-Committee of the Corrosion Committee (a joint committee of the Iron and Steel Institute and the Iron and Steel Industrial Research Council) regarding the surface preparation and painting of iron and steel. The points dealt with include the failure of paint applied over mill scale, the removal of scale by pickling, sandblasting and weathering, the choice and behaviour of paints on ordinary and on low-alloy steels, and the selection of paints for marine work. In conclusion the author describes some corrosion tests now in progress which will establish the relative values of coatings of seven different metals and alloys on flat steel plates under a variety of conditions of exposure.

**Corrosion Resistance of Steels with Varying Grain Size.** B. A. Krassiuk and I. L. Liplavk. (Comptes Rendus (Doklady) de l'Académie des Sciences de l'URSS, 1939, vol. 25, No. 3, pp. 198-200). The authors report on an investigation of the relative corrosion resistance of specimens of 0.40-0.45%-carbon steel of varying grain size. The specimens were examined under the microscope before and after treatment with a solution of iodine in benzene, and loss-of-weight determinations in 18% sulphuric acid were also made. The results showed that, up to a certain limit, grain growth in steel always increased the resistance to corrosion.

## ANALYSIS

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(Continued from pp. 214 A–215 A)

### **Methods for the Photometric Determination of Cobalt in Steels.**

H. Pinsl. (Archiv für das Eisenhüttenwesen, 1940, vol. 13, Feb., pp. 333–336). The author describes a new technique for the photometric determination of cobalt in steel. In brief, the method consists of dissolving the sample in hydrochloric acid, adding a suspension of zinc oxide in distilled water, filtering and then using a Pulfrich photometer or a Polarphot to measure the intensity of the blue colour of a portion of the filtrate. White light is used for determinations up to 20% of cobalt; for 20% to 50% monochromatic light from a mercury vapour lamp is employed. The degree of accuracy is  $\pm 0.15\%$  in the former case, and  $\pm 0.25\%$  in the latter. The time required is about 40 min. Precise details of the procedure are given.

### **The Estimation of Hydrogen in Steel and other Metals.** W. C.

Newell. (Iron and Steel Institute, 1940, see this Journal, Section I.). An account is given of the development of the vacuum-heating method of estimating hydrogen in metals (especially steel). The theoretical basis of the method is discussed, and a description of an apparatus designed for the study of the hydrogen content of metals is given, together with results of tests upon the method itself and upon metal samples. The rate of evolution of hydrogen from steel at various temperatures has been studied, and it is confirmed that the amount of hydrogen given off by this method is the same as that by the vacuum-fusion method.

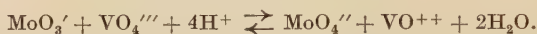
### **Vanadometric Method of Determining Iron in Ferro-Vanadium.**

V. V. Stepin and N. V. Muzovskaya. (Zavodskaya Laboratoriya, 1939, No. 8, p. 861). (In Russian). Iron in ferro-vanadium can be determined without first separating the vanadium, by titrating with ammonium vanadate using phenyl anthranilic acid as an indicator. The iron is previously reduced to the divalent state by treating the solution with hydrogen sulphide.

### **Determination of Molybdenum in Cast Iron and Steel.** C. Sterling

and W. P. Spuhr. (Industrial and Engineering Chemistry, Analytical Edition, 1940, vol. 12, Jan., pp. 33–34). A combination of the  $\alpha$ -benzoinoxime and lead-molybdate methods for the determination of molybdenum in ferrous materials is described. The critical ignition of the  $\alpha$ -benzoinoxime precipitate is avoided by dissolving it in ammonium hydroxide and precipitating and weighing the molybdenum as lead molybdate without further purification.

**Vanadometric Determination of Molybdenum and Phosphorus.** V. V. Stepin. (Zavodskaya Laboratoriya, 1939, No. 8, pp. 799–800). (In Russian). Molybdenum is reduced to the pentavalent state by mercury in hydrochloric acid solution. After filtering to remove the mercury and  $\text{Hg}_2\text{Cl}_2$ , the filtrate is acidified with sulphuric acid to give a 7*N* concentration of sulphuric acid and then titrated with ammonium vanadate solution :



Phenyl anthranilic acid is used as indicator. Vanadium does not interfere with the determination. For determining small amounts of phosphorus in ores, iron, steel, ferro-alloys, &c., the sample is dissolved, the solution is oxidised with permanganate, and the phosphorus is precipitated with ammonium molybdate reagent. After standing, the precipitate is filtered off and dissolved in ammonia, this solution is acidified with hydrochloric acid and the molybdenum is determined as described above.

**Rapid Determination of Nickel in Steels and Cast Iron.** I. M. Korenman and G. D. Voronov. (Zavodskaya Laboratoriya, 1939, No. 7, pp. 664–665). (In Russian). The dimethylglyoxime reaction is used for the colorimetric determination of nickel. It has been found that the iron need not be removed provided that it is oxidised to the trivalent state (with bromine water) and the solution contains sodium-potassium tartrate. Carbon is removed, if necessary, by filtration. It is preferable to use standard steel specimens in making up the standard solutions. A determination takes 26–31 min. The maximum difference between the gravimetric and colorimetric determinations was 0.18% in a 4% nickel alloy.

**Comparison of Some Methods of Determining Nitrogen in Alloys Containing Chromium.** B. G. Lebedev and A. M. Samarin. (Zavodskaya Laboratoriya, 1939, No. 6, pp. 635–637). (In Russian). Vacuum-melting and three distillation methods for the determination of nitrogen were compared from the point of view of the results obtained for the nitrogen content of several samples of chromium-iron alloys. The latter methods included Johnson's method (distillation with potassium hydroxide), distillation with magnesium oxide and distillation with lime. If the sample does not dissolve completely in 1 : 1 hydrochloric acid, it is recommended that the residue be fused with sodium bisulphate in the presence of concentrated sulphuric acid. Sufficiently good results are, however, also obtained if the residue is transferred to the distillation flask and distilled with concentrated caustic alkali. In carbon-free and carbon-bearing chromium-iron alloys the distillation with magnesium oxide gives results some 5–10% lower than those obtained by Johnson's method. Johnson's method, on the other hand, gives results which are higher than those obtained by melting in a vacuum.

**A Quick Method for Determining Silicon Contained in Iron and Steel.** R. Ishii. (Scientific Papers of the Institute of Physical and



Chemical Research, Tokyo, 1939, vol. 36, Dec., pp. 491-496). The rapid method for the determination of silicon in iron and steel which is described in detail in this paper consists, briefly, of dissolving the sample in hydrochloric acid, placing the solution in a suitable vessel fixed in a machine, rotating it at about 1000 r.p.m. for 1 min., and measuring the volume of the silicic acid precipitate formed. The method has a wide range of application, and a determination can be completed in 15 min. with carbon steels and about 30 min. with special steels.

**Determination of Titanium, Niobium and Zirconium in Alloy Steels.** A. A. Fedorov. (Zavodskaya Laboratoriya, 1939, No. 8, pp. 867-869). (In Russian). The "Steeloscope" spectrometer, the conditions and suitable lines for the determination of titanium, niobium and zirconium in alloy steels are described.

**The Spectrum-Analytical Method of Determining Elements in Sparks by Direct Photo-Electric Measurement of the Intensities of the Lines.** G. Thanheiser and J. Heyes. (Mitteilungen aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1939, vol. 21, No. 22, pp. 327-334). The authors describe a technique of spectrum analysis in which photo-electric cells are used as a direct means of comparing the intensities of two spectrum lines. The mean error experienced with this new method was 1.49%. By way of example, the authors describe how the technique is applied to determine manganese and magnesium in aluminium.

**Qualitative Spectrographic Analysis in the Arc, with Graphite Electrodes.** W. C. Pierce, O. R. Torres and W. W. Marshall. (Industrial and Engineering Chemistry, Analytical Edition, 1940, vol. 12, Jan., pp. 41-45). The methods and apparatus used for qualitative spectrographic analysis with a direct-current arc are described. From comparative studies of anode and cathode excitation it is concluded that anode excitation is generally preferable. The factors affecting the sensitivity of detection of an element are discussed, and sensitivity data are given for typical analyses.

**The Determination of Low Aluminium Contents in Steel and Iron by Spectrum Analysis.** G. Hartleif. (Archiv für das Eisenhüttenwesen, 1940, vol. 13, Jan., pp. 295-297). The author reports on the development of a spectrum method of determining small percentages of aluminium in iron and steel. In this method, which is described in detail, specimens were cast in a small chill and then forged down to a section of 15 × 30 mm., and these bars were used as electrodes. The determination took about 70 min., which includes the preparation of the specimen. The degree of accuracy obtained was equal to that obtained by chemical analysis.

**Sulphuric Acid Method of Determining Silica in Iron Ores.** V. A. Romaschenko, N. I. Pronenko and N. S. Tkachenko. (Zavodskaya Laboratoriya, 1939, No. 7, p. 30). (In Russian). In order to eliminate the potash fusion in platinum crucibles when dealing with a large number of samples, a direct solution method for the determina-

tion of silica in iron ore was developed. The finely ground dry sample was roasted at 700–750° C. for 10–15 min. in an electric muffle furnace. It was then dissolved by heating with hydrochloric acid (sp. gr. 1.19), the solution evaporated with sulphuric acid, the residue redissolved by warming with dilute hydrochloric acid and the silicic acid filtered off from the hot solution. The percentage of silica calculated from the weight of the ignited residue was corrected by subtracting 0.1–0.2%, depending on the nature of the ore. The method is a time-saving one.

**A Study of the Determination of the Pyrites Content and of the Total Sulphur Content in Bituminous Coal and in Waste Heaps.** F. Grimmendahl. (*Technische Mitteilungen Krupp, Forschungsberichte*, 1940, vol. 3, Jan., pp. 34–38). The author discusses and compares methods of making pyrites and total-sulphur determinations on samples of coking coal, dumped residues from coal washeries, and pyrites lumps. The methods of pyrites determination which he examined were those of Lissner and Brandeis, Parr and Powell, Lunge, Bartsch, the tin method and that of Harpen Bergbau A.G., and the methods of determining total sulphur were those of Eschka, Seuthe, the Friedrich-Alfred-Hütte, and the Krupp method.

**A Laboratory Method of Determining the Amount of Residual Sulphur in Coke.** S. G. Aronov and Kh. M. Moiseeva. (*Koks i Khimiya*, 1939, No. 4–5, pp. 51–54). (In Russian). Different laboratory methods of determining the percentage of sulphur in coke made from coking coal are described. Coking in a crucible is recommended as giving the most satisfactory results. Coking in a quartz tube with absorption of the volatile sulphur compounds did not give very reliable results for the volatile sulphur content. The results of the crucible method agreed very well with those of coking on the production scale. The elimination of sulphur from coal increases with the amount of volatile material in the coal, and also depends on the proportions of the different forms in which sulphur is present in the coal.

**The Determination of the Benzol Content of Wash Oils.** W. Brösse. (*Technische Mitteilungen Krupp, Forschungsberichte*, 1940, vol. 3, Jan., pp. 2–12). The author presents an account of an investigation of improved methods of determining the amount of light oils present in the wash oil used in coke-oven by-product plants. The method of distillation using fine-fractionating columns which is here described produced reliable and accurate results.

## BOOK NOTICES

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(Continued from pp. 268 A-270 A)

CAMM, F. J. "*A Dictionary of Metals and their Alloys.*" 8vo. Pp. 245. London, 1940 : George Newnes, Ltd. (Price 5s.)

In his preface the editor states that, so far as he is aware, this is the first alphabetically arranged dictionary pertaining to metals that has yet been published, and that in view of the large number of alloys in modern use, a book of this type should fill a want for reference purposes among engineers and others.

The editor has flung his net fairly wide, especially in the non-ferrous field, and the names of a large number of alloys both of foreign and of domestic origin are listed. Unfortunately the data given concerning the alloys, usually only the composition, are not always accurate, and the value of the dictionary as a reference book is thus largely nullified. Very many examples of such inaccurate items could be cited, but it will suffice here to point out that the "electron" alloys do not contain copper, that "blister steel" is not the result of cooling raw steel slowly, and that "ferro-nickel" is not used for making nickel steels. Matters are no better when the dictionary departs strictly from its title and gives definitions of some technical terms. Thus, "sonorousness" has nothing to do with "tin cry," metals having a crystalline fracture are by no means devoid of tensile strength, and stellite is not hardenable by heat treatment.

A dictionary of this type should primarily be a collection of accurate data; therefore it cannot be said that this book fulfils its function, and its deficiencies in this respect must largely be ascribed to lack of care in verifying the facts presented.

In a section at the end of the volume is a series of short articles on the surface treatment of metals by plating, polishing, spraying and colouring, and an account of the heat treatment of tool steels. These sections are generally accurate, and give information adequate for the performance of the various operations on a workshop scale.

STEPHEN L. ROBERTON.

"*Centraal Instituut voor Materiaalonderzoek.*" Mededeling No. 19. Centrale Corrosie Commissie. "Tweede Verslag van Corrosie Commissie IV voor de Bestudering van Beschermende Deklagen van Ijzerconstructies. Onderwerp : Ijzerconstructies in de Atmosfeer Bescherming met Verf." Deel I : "Tekst." 8vo. Pp. 128. December, 1939. Deel II : "Tabellen, Grafieken en Figuren." December, 1939. (Price, 4.50 florins.)

This Report contains a further account of the investigations of the Dutch Corrosion Committee on the protection of structural iron and steelwork by means of paints. The results already obtained in them are of much scientific interest and practical value, and may usefully be compared with the findings of the Protective Coatings Subcommittee of the Corrosion Committee of the Iron and Steel Institute and the British Iron and Steel Federation. For instance, the following statement, based on routine inspections of painted steel structures, is made by the Dutch Committee : "It has been found to be possible to protect steel structures exposed to the atmosphere so effectively that

for some years (according to the experience of the committee at least 5 years) even no subsurface rust occurs, by sandblasting the material and then applying a priming coat of red lead followed by a finishing coat." On p. 306 of the Fifth Report of the Corrosion Committee the Protective Coatings Sub-Committee wrote: "... it would not be unreasonable to expect that a structure painted in accordance with the principles indicated above" (which are identical with those recommended by the Dutch Committee) "would be adequately protected against normal atmospheric corrosion for 5 years." This concordance of views and observations in the two countries should remove any doubts that may yet linger in the minds of practical men as to the value of adopting the principles in question when painting structural iron or steel-work.

The first series of field tests on painted specimens by the Dutch Committee has now been in progress for three years. The observations made after this period are in general agreement with the earlier results given in their First Report (see Journ. I. and S.I., 1938, No. II., p. 186 A), and need not be referred to in detail again. They have now attempted, however, to correlate the rate of deterioration of paint on steel with the local meteorological conditions. They consider that no general correlation exists, but observe that at their four home stations in Holland the "aggressiveness of the atmosphere" to painted steel varies with the electrical conductivity of the rain-water; they are extending their observations to four new stations in order to check whether this is a general law or not. Sunlight has little effect on the rate of paint failure in Holland, but atmospheric moisture and rain-water play an important part. For instance, paint failure is most rapid on the lower horizontal surfaces of their specimens which face the ground (they use bent specimens with one part horizontal and the other dipping down at 45° towards the South). This is attributed, probably with reason, to the slow evaporation of the dew condensed on this part of the specimens; in this connection it may be noted that G. Schikorr has shown that dew deposited on metal surfaces in urban atmospheres rapidly takes up sulphur dioxide from the air and becomes markedly acid.

Two further series of tests were commenced in 1938. These are concerned, respectively, with priming paints for iron and steel, including an aqueous asphaltic bitumen emulsion and paints made up in binders containing chlorinated rubber or artificial resinoids, and with finishing paints. Their laboratory investigations, dealing chiefly with control and acceptance testing, have been continued.

It may be repeated that the Report contains a good deal of important information, and those concerned with the use of paints for structural work would be well advised to study it. The Report is naturally in Dutch, but ample summaries in English, French and German have been provided; indeed, in view of the general similarity between Dutch and German, anyone with a knowledge of the latter should have no difficulty in following the tables and diagrams, or even in reading selected parts of the text.

J. C. HUDSON.

ROSENBERGER, W. A. "*Impact Cleaning*." First Edition. 8vo. pp. xiv + 466. Illustrated. Cleveland, Ohio and London, 1939: Penton Publishing Co. (Price 38s. 6d.)

This book is the first in its field, so far as the reviewer is aware and it can be said here that it will probably be the standard treatise on the subject for a long time to come. The author very evidently knows his subject intimately, and, what is even more satisfactory, knows how to write an informative book about it.



There are forty-four chapters, generally short, and these are grouped in three sections covering nozzle blast cleaning, mechanical impact cleaning, and the ventilation of impact cleaning equipment, respectively. The cleaning of metal objects by mutual impact in tumbling barrels is not dealt with. Each item of equipment and each aspect of design or manipulation is dealt with in a separate chapter, and there are numerous line diagrams to assist the reader in following the text. The theory and practice of impact cleaning are clearly dealt with, and much useful information regarding costs, maintenance and power requirements is interpolated throughout the work, in addition to being specifically treated in individual chapters.

In his treatment of the subject the author displays a marked impartiality, and is content to base his views on first principles backed by experience in operation. His keen interest in and intimacy with every factor involved in impact cleaning are continually discernible throughout his work, and the style is almost conversational. At the end of the book a most unusual assortment of data is given in an appendix, a useful trilingual glossary of technical terms being included, and, for some unknown reason, a Greek alphabet.

Those interested in any form of impact cleaning will naturally take the earliest opportunity of reading this volume, and they must consider themselves fortunate in having such an informative and comprehensive work available as a text-book.

STEPHEN L. ROBERTON.

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# SUBJECT INDEX.

[References to the papers read before the Institute are indicated by the word *Paper* following the page number. The letter *P.* denotes a reference in Section I. of the Journal, which contains the reports of the proceedings of meetings, the papers read, and the discussions thereon. The letter *A.* denotes a reference to the section dealing with abstracts.]

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